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THE IMPACT OF NUTRIENT MANAGEMENT OPTIONS ON SOIL ORGANIC CARBON POOLS AND MAIZE YIELD IN NORTHERN GHANA

BY

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INTEGRI PROCEDAMUS

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN SOIL SCIENCE.

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DECLARATION

I hereby declare that, except for references to other peoples work, which have been duly cited and acknowledged, this thesis is the result of my own original research and has not been presented elsewhere either in part or in whole for another degree.

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DEDICATION

I dedicate this work to my mother Florence Tettey for her spiritual and physical supports.

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Glory be to the Almighty God for His love, abundant grace and mercy upon my life without which this thesis would not have been completed successfully.

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ABSTRACT

Exponential growth in human population has led to the exploitation of natural resources e.g. organic matter reserves for crop production. Various interventions such as manuring, fertilization, green manuring etc. have been proposed to enhance continuous crop production. However, the sustainability of these methods are unknown. Soil productivity depends largely on organic carbon stocks (SOC). The labile organic matter fraction or pool is associated with nutrient dynamics and responds sensitively to changes in management namely tillage, manuring, fertilization, mulching, etc. The objective of the study was two-fold: first to investigate the impact of three management practices, namely: manure application, fertilizer application and farmer practice (no fertilization application) on SOC fractions and the total SOC (TOC) and second, how these practices affect maize production at three sites: Nyankpala, Dimabi and Savelugu, in the Northern Region of Ghana.

The procedure involving permanganate oxidizable carbon (POXC) was used to determine labile and non-labile pools of SOC of soils for each management practice. Changes in percentage carbon is used to determine Carbon Pool Index (CPI) which expresses the changes in the labile pools of soils under management relative to that of a virgin soil and Lability Index which is a measure of good soil conditions (LI). These two indices were used to estimate a Carbon Management Index (CMI) which is used in studies to monitor both soil degradation and agricultural yields.

Results indicate that nutrient levels increased in the order; manure >> fertilizer >> non-fertilizer Also, the carbon pool index (CPI) values which indicate the extent of degradation and rehabilitation were in the order Nyankpala >>> Dimabi >> Savelugu (fertilized) > Savelugu (non-fertilized). In addition, CMI were 50.6, 47.6, 39.9 and 24.9 for Nyankpala, Dimabi, and Savelugu, respectively. The results show that management affected mainly the labile carbon pool. The relationship between labile carbon (C_L) and TOC for Nyankpala was: $C_L=0.003 \times TOC^2-0.0023 \times TOC+0.0219$; $R^2=0.81$ that for Dimabi was $C_L=0.0199 \times TOC^{-0.058}$: $R^2 = 0.93$ and that for

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Savelugu were, C_L=0.02 x $TOC^{-0.088}$: R^2 =0. 90 and C_L=0.0005 x TOC^2-0.0008 x TOC+0.0212 R^2=0.91 for Fertilized and non-fertilized, respectively. The application of manure at Dimabi, manure Nyankpala, fertilized farm and non-fertilized farm yielded 2701.56 kg/ha, 2267.37 kg/ha, 2944.81 kg/ha and1060.24 kg/ha respectively. The findings suggest that manure management practice had significant impact on maize yield and this in turn was via the C_L but not the TOC. With exception of fertilized field at all sites, the maize yield correlated well with the C_L. Thus given a management practice and the manner it impacts on C_L, maize yields could be predicted if other climate variables do not constraint the production.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Exponential growth in human population all over the world has led to the exploitation of organic matter stocks for crop production. Productivity of agricultural systems depends largely on soil organic matter (SOM) reserves. Continuous cultivation in most cases leads to the decline of organic matter and structural deterioration (Resck *et al*., 2008).

Soil Organic Matter (SOM) consist mainly of plant and animal residues at various stages of decomposition and which has been synthesized microbiologically and chemically from the breakdown products and of the bodies of microorganisms and animals (Schnitzer, 1991). Its ability to promote soil aggregation (Oades, 1984), enables it to reduce soil erosion as well as enhance the soil's capacity for greater moisture infiltration and retention (Livelle, 1988). In addition, SOM is known to increase the availability of nutrient in the soil by forming chelates with calcium, magnesium, potassium, and ammonium, a property that is necessary for crop production. As a result of its association with fertility and soil quality, SOM content of a soil is the yardstick to measure soil productivity. It is therefore desirable to increase total organic matter stocks of soils and to monitor its reduction resulting from soil management practices

Over the years, most studies use total organic carbon (TOC) values to assess the impact of management on soil and crop productivity (Roscoe and Buurman, 2003) however, it is now increasingly evident that certain pools or fractions respond to management more than TOC (Lefroy *et al.*,1993)

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Fractionation of organic matter reveals that the SOC exists in different fractions with different half-life periods and degrees of protection (Duxbury *et al.,* 1989). The heavy fraction consists of materials with higher half-life in centuries (Post *et al,* 2001), thus the inherent nutrients of this fraction are not readily accessible in the short term though plays a role in cation exchange capacity (Lee *et al.,* 2009). The labile fraction (C_L) however has shorter half-life period of few months and is associated with the nutrient dynamics of the soil. The reactivity of this fraction coupled with its short half-life also makes it to respond more readily to changes in plant vegetation and management practices such as tillage, manuring, fertilization, crop rotation and other interventions than total organic carbon (TOC) values (Bongiovanni and Lobartini, 2006).

For example Bowman *et al.,* (1990) observed 55% nutrient losses in soil cultivated for over 60 years with more than half of this decline occurring in the first three years and was associated with the C_L rather than TOC.

Thus to establish the nutritional status of a particular soil, it is important to develop methods that can estimate SOC fractions and possibly derive procedures that can estimate SOC fractions from the more easily and routinely measured TOC.

1.2 Problem Statement

Soils at the Northern region of Ghana are inherently low in fertility and are dominantly coarse textured. High ambient temperatures coupled with fast decomposition of low input of crop residues have led to a drastic decline in SOC, hence low crop yields. Moreover, some farmers' soil management practices such as burning of crop residues or removal to feed animals, manuring, and cropping without soil amendment do not improve SOC. To improve crop yields and the standard of living of smallholder farmers, developing a sustainable soil management system is crucial. From the foregoing, it is clear that SOC management, especially the C_L component is very

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important for sustained crop productivity. It is hypothesized that knowledge of C_L from fractionation studies would enable the prediction of crop growth and yield. Currently there is paucity of data on labile C pools of these soil management systems in Northern Ghana.

1.3 Objectives of the study

The objective of the study were to:

1. investigate the impact of three management practices on SOC fractions in three farming communities in northern Ghana.

2. investigate the relationship between the SOC fractions and maize yield, and

3. derive a simple relation for estimating the labile carbon from TOC determinations.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Soil Organic matter (SOM)

Soil organic Matter (SOM) comprises the sum of all organic substances such as plant and animal residues at various stages of decomposition which has been synthesized microbiologically and chemically from the breakdown products and of the bodies of microorganisms and animals (Schnitzer, 1991)

Soil Organic matter (SOM) when mineralized by microorganisms renders it as a major source of plant nutrients in soils with little inherent mineral fertility (Sanchez et al., 1989). It is also known to boost the activities of microorganisms and soil fauna serve to promote soil aggregation (Oades, 1984), which help to reduce soil erosion (Lal, 1986), as well as enhance greater moisture infiltration (Livelle, 1988). In addition, it increases the availability of nutrients in the soil by forming chelates with calcium, magnesium, potassium, and ammonium. Furthermore, it has also been known to act as a sink for carbon when it remains undecomposed and also as a source when decomposed (FAO, 2000). Thus, maintenance of soil organic matter in low-input agro-ecosystems has been noted to promote nutrient retention and storage (Russell, 1973; Woomer and Ingram, 1990), and for that matter it is considered an important part of soil for its high contribution to soil productivity and quality.

Generally, the total carbon comprises soil organic carbon (SOC) and soil inorganic carbon (SIC). The SIC is derived from carbonates and other C containing weathered minerals. Soil organic carbon is the focus of this study a complex and dynamic group of compounds formed from the carbon originally harvested from the atmosphere by plants during photosynthesis is transformed into forms useful for energy and growth (Schlesinger, 1997). Organic carbon then cycles from the

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plant to the soil where it becomes an important source of energy for the soil ecosystem, driving many other nutrients cycles. Soil inorganic carbon is the result of mineral weathering and forms a small proportion of many productive soils.

Soil organic carbon consists of different fractions namely; the heavy fraction and the light fraction. The heavy fractions are composed of polysaccharides and humic substances which are often stabilized in clay minerals and silt sized particles (Schlesinger, 1997).

Physical fractionation of heavy fractions based on density differentials and sizes reveals two sub fractions called pools. Those with size ranging between 53-2000 nm accurately describe the slow pool while those finer than 53 nm fall into the category of the passive pool (Cambardella and Elliot, 1992). They are known to have low sorption capacity, highly humified and physico-chemically protected against decomposition which affects the physical properties of the soil. They are chiefly involved in cation exchange capacity (Lee *et al.*, 2004).

The Light fraction which is also known as the labile soil organic carbon (Labile SOC or C_L) on the other hand consists of rapidly mineralized components. The most labile components are cellular contents, such as carbohydrates, amino-acids, peptides, amino-sugars and lipids. Labile soil organic matter also includes less readily metabolized structural materials, including waxes, fats, and resins, lignin and hemicellulose. Part of the labile soil organic matter consists of microbial metabolites and biomass, which can be estimated through fumigation-incubation (Jenkinson *et al*., 1976; Jenkinson and Ladd, 1981) or fumigation-extraction (Vance *et al.*, 1987) techniques. Studies show that the Dehydrogenase activity could be used as an estimate of the microbial activity which measures the microbial biomass in the soil.

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2.2. Formation process of SOM

Soil organic carbon (SOC) is a dynamic group of compounds that have their origin in the photosynthetic activity of trees, grasses, shrubs, forbs and legumes. The carbon in these compounds cycles through solid forms back to the atmosphere at different rates, with turnover times ranging from months to hundreds of years (Davidson and Janssens, 2006; Six *et al*, 2002).

During photosynthesis, plants reduce carbon from its oxidized form into the organic forms useful for growth and energy storage (Schlesinger, 1997). Some of this carbon fixed from the atmosphere in time becomes soil carbon through the processes of above and below ground decomposition, root die-off, and the release of sap exudates from plant roots into the soil (exudates contain carbohydrates). Photosynthesis also provides the raw materials for indirect imports of Carbon-rich materials onto and into the soil. Soil carbon includes soil inorganic carbon (SIC) in the form of carbonates. Soil inorganic carbon is the result of mineral weathering, and is less responsive to management than SOC, turning over much more slowly (Izaurralde, 2005). Soil inorganic carbon content is low in many productive soils.

Soil microbial biomass carbon forms 1 – 3% of total soil carbon. Soil organic matter determines soil fertility and stability (Herrick and Wander, 1998). Most SOC is found on the top of the soil profile, due to the presence and influence of biotic processes there, with approximately 64% of soil carbon in the top 50 cm (Conant *et al*., 2001). Soil organic carbon accumulation is positively correlated with precipitation and negatively correlated with temperature (Jones, 2007). The stock of SOC accumulation is highest in cool, wet conditions (Schlesinger, 1997) and lowest in deserts. Soil carbon stocks are positively correlated with the presence of clay and iron and negatively correlated with the bulk density of soil.

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The rate of carbon sequestration is determined by the net balance between carbon inputs and carbon outputs. Carbon inputs and outputs are affected by management and by two (2) biotic processes: (i) production of organic matter in the soil and (ii) decomposition of organic matter by soil microorganisms. The biotic processes are strongly controlled by physical, chemical and biological factors including biome, climate, soil moisture, nutrient availability, plant growth and erosion (Post *et al.,* 2001; Derner and Schuman, 2007; Jones, 2007; 2008; Ingram *et al.,* 2008).

Soil CO_2 is the main end product of the decay of SOC. Under aerobic conditions CO_2 is produced by respiration of bacteria and protozoa in the guts of insects, and bacteria and fungi in the soil (Singer and Munns, 1987). Soil CO_2 production accelerates with temperature and with exposure of soil organic matter to air in pore spaces and on the surface of the soil. When decomposition and soil CO_2 production is slowed, the net rate of the soil carbon accumulation and storage may increase.

2.2.1 Additions of SOM

Many soil properties that constitute soil quality are directly affected by the presence of organic matter. Increasing soil organic matter therefore leads to the improvement of soil properties (Rochette *et al.,* 2002).Hudson,(1994) confirms that SOM is the repository of nutrients particularly Nitrogen (N), Phosphorus (P), Sulphur (S) and micronutrients and during its turnover contributes to fertility and locations in the profile that are difficult to achieve with inorganic amendments. Dick *et al*., (1998) also confirms that when manure was added to maize grain and silage plots it help to maintain soil organic matter concentration. On the other hand, McLaughlin *et al.,* (2002) established that increasing levels of SOM can affect the economy of farming practices other than boosting soil fertility. Thus farmers reported noticeable decrease in power requirement for tillage practice after several years of manure application or conservation tillage

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practices. Also, it was noted that over several years amendment with inorganic fertilizers (100 or 200 kg N/ha/year) and fresh stockpiled (50 and 100 Mg wet weight/ha/year),plots receiving manure amendments at the high rates exhibited 27-37% lower draughts and 13- 18% lower tractor fuel consumption than those receiving inorganic fertilizer (McLaughlin *et al*.,2002).

2.2.2 SOM Losses

It is known that world soils contain about 1,500 to 2000 Pg (1 pecagram= 1billion metric tonnes) organic carbon and 800 to 1000 Pg of inorganic carbon as carbonates content is generally high in vegetation. Lal, (1995) asserted that soil carbon is generally high in virgin soils under grass or forest vegetation. When forestland or grassland is converted to cropland and pastures great deal of organic C is lost. Over the years carbon losses have been associated with low production levels and exacerbated by intensive tillage. Biomass burning, inadequate use of fertilizers and organic amendments, removal of crop residues, low protection of soils against erosion and other factors are known to degrade soils. Studies conducted by Cole, (1996) estimated that loss of soil organic carbon from cultivated soils of the world range from 41 Pg to 55 Pg. When a natural ecosystem is converted into agriculture land about (60-70%) of organic matter is lost in the process. It has been noted that the loss of organic matter when native ecosystem is converted into arable agricultural land is attributable to four factors (Lal *et al*., 1998).

(i) the amount of organic carbon returned to the soil in plant litter is often lower in agricultural systems than in native systems. Thus in agricultural production part of the organic material in the crop is removed and harvested from the system.

(ii) when a native land is converted into agricultural production there is a change in plant species composition. This change results also in changes in shoot and root biomass.

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(iii) Agricultural production often results in a change in soil conditions (disruption of stable, protected SOM by tillage) and the effect of climatic conditions (moisture and temperature) promotes greater mineralization than under native uncultivated soils.

(iv) There is redistribution and subsequent losses of finer particles of soil which are rich in labile SOM due water, wind and tillage erosion process.

2.2.2.1 Effects of burning on soil carbon

It is known that humans use fire to clear areas for agriculture and to clear crop residues. Studies conducted by Maia and Riberio, (2004) reveal that burning keeps organic matter and nutrients from returning to the soil. This results in a decrease in soil organic matter under traditional cropping systems in the long term. Occurrence of wildfires in forest ecosystems has been found to have lasting impacts on the microbial composition as well as the organic matter and its dynamics (Pastor and Post, 1986). This also invariably affects productivity and community structure of microbes. .In general bacteria are more tolerant to heat than fungi; therefore, it is usually observed that burning favours bacteria over fungi (Deka and Mishra, 1983)

Crutzen and Goldammer, (1993) stated that the effects of fire does not only release of CO_2 and other greenhouse gases to the atmosphere but also results in the depletion of ecosystems' aboveground biomass, including the organic topsoil horizons, composed mainly of plant litter which includes the labile organic matter pools. The effect of fire on carbon, however, depends on its characteristics namely its speed and intensity (Knapp, 1985). These factors will obviously be influenced by the state of vegetation, which is its maturity and woody component, accumulation of litter and climatic factors such as moisture level. All the above ground material that is fully combusted will be lost from the system. Pyne (2001) also confirmed that burning increases available nutrients in soil. This is due to the fact that all the nutrients now exist in the water-

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soluble components of ash that are now more readily available to living organisms. Ferna´ndez *et al.,* (1999) observed that alterations occur in the mineralization indices of some soils lasting at least for 2 years after a wildfire. In one study burning was used to clear forest, 4t C/ha was lost in the top 3cm of the soil but this was replaced within one year under pasture system (Chone *et al.,* 1991).

2.2.2.2 Residue decomposition and factors affecting it

Decomposition involves a series of biochemical processes that lead to the reduction in the complexity of a material. When organic residues are returned to the soil they undergo biological processes which involve the physical breakdown and biochemical transformation of complex organic material into simpler but newly synthesized compounds which are lower in molecular mass (Juma, 1998).This process is however an interactive biochemical process which involves the influence of environmental factors, organisms living in the soil and the quality of the substrate. The microbial decomposition of residues and organic matter is facilitated by enzymes which are protein catalyst produced by living cells which speed up chemical reactions. Enzymes occur intracellular in all living microbial cells (Zhao *et al.,* 2010; Yuan & Yue, 2012). Moeskops *et al*., (2010) stated that enzymes are also known to be tightly linked with microbial oxido-reduction processes. Soil enzymatic activity plays an important role in catalyzing reactions indispensable in life processes of soil microorganisms, decomposition of organic residues, circulation of nutrients, as well as forming organic matter and soil structure. Examples of enzymes are oxidoreductases, hydrolases, isomerases, lyases and ligases among others. Each of them plays key biochemical functions in the overall process of material and energy conversion (Gu *et al.*, 2009). Though many enzymes are important in their activity in the soil environment, dehydrogenases (DH) are one of the most important, and the dehydrogenase activity is an indicator of overall soil microbial activity (Gu et al., 2009 and Salazar *et al.,* 2011). Zhang *et al*. (2010) stated that DH plays a significant

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role in the biological oxidation of soil organic matter (OM) by transferring hydrogen from organic substrates to inorganic acceptors. Many specific DH transfer hydrogen to either nicotinamide-adenine- dinucleotide (NAD) or nicotinamide-adenine-dinucleotide-phosphate (NADP). Brzezińska *et al.* (2001) found that active DH can utilize both O_2 and other compounds as terminal electron acceptors, although anaerobic microorganisms produce most DH. Consequently, DHA reflects metabolic ability of the soil and its activity is considered to be proportional to the biomass of the microorganisms in soil. According to Yuan and Yue, (2012) evidence exist that soil enzymatic activity strongly correlates with soil OM content. Thus higher OM level can provide enough substrate to support higher microbial biomass, hence higher enzyme production.

The environmental factors such as moisture, temperature are able to accelerate the decomposition if residues when the residues have enough available nitrogen for microbes to use as a source of energy (Wilson and Hargrove, 1986).Other factors such as soil pH, soil texture and management practices also affect the decomposition. The process leads to the release of carbon dioxide from the native soil, energy, water, plant nutrient, as well as newly synthesized organic compounds. This process leads to recycling of nutrients back into the soil. (Duxbury *et al.*, 1989). The decomposition process is summarized below:

$$C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O+\text{Energy.} \qquad [2.1]$$

The decomposition rate of organic matter is affected by the chemical and physical properties of the residue (Rice *et al*., 2004). Duncan (1996) asserted that materials with high levels of lignin degrade very slowly whiles those with very little amounts of lignin degrade rapidly. This is attributed to the fact that lignified materials are very resistant to microbial action. Similarly, residues that are rich in polyphenols and tannins degrade more slowly than those with high contents of water soluble materials and cellulose (Taylor *et al.,* 1989).

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Plant residues contain complex mixture of soluble sugars, free amino acids, proteins, cellulose, hemicelluloses and lignin (White, 1979, Rice *et al.*, 2004). Most residues that contain sugars starches and proteins decompose rapidly, whereas those containing cellulose, fats, waxes and resins decompose slowly. Thus residues from different sources, plant species decompose at different rates. A study conducted by Kaboneka *et al.* (1997) revealed that when wheat straw, corn stover and soybean stubble were incubated for 30-day period the rate of mineralization was discovered in the order 48%, 56% and 60% confirming that the decomposition rate of plant residues is directly affected by their chemical and physical properties. Brady, (1990) noted that the chemical composition of plant residues change as it ages: the amount of N, proteins and water soluble substances decrease while the proportions of cellulose, lignin and hemicelluloses increase thereby reducing the rate of decomposition.

The nitrogen content of substrate have is a factor that govern the rate of decomposition (Cowling and Merrill, 1966; Mellilo, 1980).The rate of decomposition correlates negatively with residues containing smaller amounts of nitrogen. According to Vigil and Sparks (2002) when corn cobs, corn stalks, sorghum stalks, soybean and sunflower stems were incorporated into moist soil the rate of decomposition was very slow. However, high nitrogen content of some residues lead to rapid decomposition of the residues.

There are also differences among species of grasses regarding the amount of nitrogen that is available for decomposition. Vallis and Jones (1973) asserted that leaves and litter of legumes *Desmodium intorturn* cv Greenleaf and *Phaseolus atropurpureus* cv Siratro has similar N and lignin content. The N mineralized from the former was less than that from *P.atropurpureus* and therefore attributed it to a much higher polyphenol content of the *D. intorturm*. Bartholomew (1965) and Mahendrappa (1978) also demonstrated that the addition of elemental nitrogen to natural litter materials and incorporated crop residues respectively enhance their rate of

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decomposition. The C/N ratio in plant material is variable, ranging from 20 to 30 for legumes and farm manure to as high as 100 in certain strawy residues (Garcia and Christensen, 2006).On the contrary, C/N ratio of the bodies of microorganisms is not only more constant but narrower, falling between 4 and 10 (Garcia and Christensen, 2006).The use of low quality material with a C/N ratio greater then 23, result in nitrogen immobilization (White, 1987). Juma and McGill *et al*. (1986) asserted that with respect to climate, soil conditions and the plant materials entering into soils, C:N ratio of organic matter as a whole is quite stable and differ little and ranges from about 8-10:1.

Thompson and Troeh, (1978) observed that when organic matter with C: N ratio greater than 30 is added to soils, there is immobilization of soil nitrogen at the initial stage of decomposition process. However, if the organic matter has C: N ratio of less than 20, an early release of mineral nitrogen is noted at the early stage of decomposition process. For values between 20 and 30, there may be neither immobilization nor release of mineral nitrogen. During the initial stages of the decomposition of fresh material, there is a rapid increase in the number of heterotrophic organisms accompanied by a large evolution of carbon dioxide. As decay proceeds, C: N ratio narrows and the energy supply (carbon) diminishes. Some of the microbial populations die because of the decreased food supply, and ultimately, a new equilibrium is reached (Tisdale and Nelson, 1966). When the new equilibrium is reached, there is the release of mineral nitrogen in the soil resulting in the final soil having nitrogen higher than the original. The time required for the decomposition cycle to run depends on the quantity of organic matter added, the supply of utilizable nitrogen, the resistance of the material to microbial attack (the amount of lignin, waxes and fats present) and temperature and moisture level of the soil (Tisdale and Nelson, 1966).The critical C: N ratio for net N mineralization to occur is to be less than 20-30, whereas C: N ratios greater than 30 would favour net N immobilization (Alexander, 1977).

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As indicated, residue decomposition is affected by environmental factors. Investigations conducted by Ladd and Amato (1985) revealed climate patterns contributed to differences in the time scales for the decomposition of leguminous materials in southern Australian, Nigeria and United Kingdom although the decomposition showed similar pattern (Jenkinson and Anyaba,1977). Temperature is a key factor controlling the rate of residue decomposition. Alexander (1977) established in his studies that most microbial species responsible for decomposition have optimum temperature are at their best. Mesophilic bacteria, actinomycetes and fungi have a temperature optima range of 0 to 45 ℃, while the thermophilic ones range between 45 to 60 °C. It stands to reason that a change in temperature will alter the composition of the species of the active microfora, the total number of species and also the total microbial cells. Several studies conducted revealed that activity of microbes on organic substrates increases with increasing temperature (White, 1987; Paul and Clark, 1989).

Decomposition rate of organic matter generally increases with warmer climates and lower rate of decay is observed in cool regions within belts of uniform moisture condition. In general, decomposition rates double for every 10 ° C rise in temperature. (Brady, 1990). Increased temperature is associated with greater carbon dioxide release during decomposition process. Microbial activity is known to increase with increasing temperature until there is some interference with the life processes of the microbes or unless the soil dries up (Bowman *et al*, 2002). At temperature above 50 °C. decomposition is controlled probably more by chemical than biological processes. Irrespective of the type of decomposition process global warming would likely lead to increased C loss from many terrestrial ecosystems (Jenkinson *et al.*, 1991).

There is some limited evidence indicating increased temperature increased carbon storage of source temperate region boreal forest soil (Liski *et al*., 1999).Whereas this observation may appear to contradict the general reports, it could be noted temperature would decompose the accumulated

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residue in the vegetation type and to SOM and this would be expected to continue until fresh organic matter pools become exhausted.

Alexander (1977) observed that increasing temperature generally increases the kinetic energy of substances and thus could shorten the time required to attain maximum rate of carbon dioxide evolution. Thus, since the composition of the microflora varies from locality to locality and is also altered even in single site treated with different plant residues, a single optimum for organic matter decomposition cannot be found. Instead, a wide range, 28 to 40° C has been postulated, (Alexander, 1977). Below 25° C, the rate of decomposition will accelerate with increased temperature. The high rate of organic matter decline in tropical soils has been attributed to the higher temperatures than in the temperate regions. Above 40° C, organic matter decomposition again slows down, except where thermophilic organisms abound (Alexander, 1977).

Soil moisture is another important factor that controls soil microbial activity as well as decomposition. Microorganisms differ in their response to the environmental moisture. Generally, actinomycetes and fungi are relatively tolerant to low moisture levels. It is known that an active micro-flora is maintained down to a soil moisture potential of approximately-1500 kPa while bacteria become inactive below-800 to -1500 kPa (Wilson and Griffin, 1975). Maximum microbial growth and activity require the presence of sufficient water and therefore decomposition of organic matter is very slow in dry soils. On the other hand, because oxygen is required in microbial metabolism, decomposition is faster under aerobic conditions. According to Yoshida, (1975) at very high moisture contents, the rate of microbial activity and decomposition are decreased due to lack of oxygen. As saturation of the soil with water impedes the diffusion of oxygen into the soil microbial respiration is adversely affected.

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Decomposition is known to be slow when soil water content is less than 40% water holding capacity, and stops in soils that are air dried (Vigil and Sparks. 2002).Glenn *et al.* (1993) also asserted that decomposition is dependent on soil moisture content. White, (1987) also observed that in swampy areas, slow rate of decomposition results in the formation of peat which contains high organic matter. When soils become waterlogged they impede the loss of organic matter with the accumulation of large amounts of organic acids as intermediates of the decomposition process.

Soil pH is one factor that affects the soil microbial population structure and hence activity. Work done by Alexander (1980) indicates that population shifts from bacteria to actinomycetes and then to fungi as soil pH declines, although acid tolerance of individual species vary. Carbon mineralization is most rapid in slightly alkaline soils. Soil pH has little effect except below 4 when the decomposition rate slows in humus and many upland peat (White, 1979).The treatment of acid soils with lime accelerates the decay of organic matter (Edmeades *et al.*, 1981).Thus liming of acid soils enhances carbon dioxide volatilization.

According to Thompson (1957) when the percentage of carbon and nitrogen is written as a ratio, it's termed the carbon: nitrogen (C: N ratio).This expresses the relative quantities of carbon and nitrogen in fresh organic materials or in the whole soil body. McGill *et al*. (1986) asserted that with respect to the climate ,soil conditions and the plant materials entering into soils, C:N ratio of organic matter as a whole is quite stable and differ little from ranges from about 8-10:1.

Thompson and Troeh, (1978) observed that when organic matter with C: N ratio greater than 30 is added to soils, there is immobilization of soil nitrogen at the initial stage of decomposition process. However, if the organic matter has C: N ratio of less than 20, an early release of mineral nitrogen is noted at the early stage of decomposition process. For values between 20 and 30, there may be neither immobilization nor release of mineral nitrogen. During the initial stages of the

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decomposition of fresh material, there is a rapid increase in the number of heterotrophic organisms accompanied by a large evolution of carbon dioxide. As decay proceeds, the C: N ratio narrows and the energy supply (carbon) diminishes. Some of the microbial populations die when food supply decreased, and ultimately, a new equilibrium is attained (Tisdale and Nelson, 1966).When the new equilibrium is reached, there is the release of mineral nitrogen in the soil resulting in the final soil having nitrogen higher than the original. The time required for the decomposition cycle to run depends on the quantity of organic matter added, the supply of utilizable nitrogen, the resistance of the material to microbial attack (the amount of lignin, waxes and fats present) and temperature and moisture level of the soil (Tisdale and Nelson,1966). The critical C: N ratio for net N mineralization must be less than 20-30, whereas a C: N ratio greater than 30 would favour net N immobilization (Alexander, 1977).

2.3. Ecological and Management effects on SOC storage

In simple terms carbon storage is the balance between the inputs of plant materials and losses from decomposition and mineralization processes (Paustian *et al.*, 1997). According to Jones *et al*. (2006) soil organic carbon (SOC) concentration range from as low as 5 g/kg in coarse textured or tropical soils to 35 g/kg in praire grassland soils, up to 100 g/kg in poorly drained soils (Stevensons, 1986). Under moist soil conditions, it is possible to build up the total SOC to very high levels (Magdoff and Weil, 2004). Also, SOC pool varies widely among ecological zones, being higher in cool and moist zones than in warm and dry region (Eswaran *et al.*, 2000). The capacity for SOC storage is governed by many factors including, climate, soil type, topography, vegetation inputs, and soil management (Carter, 1996)

Low mean annual temperatures and oxygen deficiency and tend to slow decomposition and thus highest SOC levels are generally found at extreme latitudes short of the permafrost region near

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the poles (Magdoff and Weil, 2004). Generally, high rainfall tends to increase plant growth more than it does decomposition, therefore, SOC tend to be positively correlated with annual precipitation. Theng *et al.* (1989) and Weil (1984) observed that SOC levels are highest (<30 g/kg) where the ratio of mean annual temperature (in ^{o} C) to annual precipitation (in mm) multiplied by 0.01 is less than1. As the ratio reaches 3 or more, SOC declines to very low levels.

The environmental climate sets overall constraints on SOM level by acting as a proximal control over net primary productivity and decomposition, but the influences of climates on SOC storage is normally modified and sometimes overridden by soil physicochemical characteristics and topography (Magdoff and Weil, 2004).

Edaphic factors such as porosity, texture, structure, slope, aspect, elevation, and landscape are also important factors, often accounting for large differences in SOC accumulation within small distances (Brajda *et al*., 2001).Wetland Histosols are the most extreme examples of the influence of topography on SOC, as these soils occur mainly in the lowest landscape position where accumulation of run-off water leads to accumulation of 150 to 1500 GC/kg in the surface layers that may be several meters thick (Magdoff and Weil,2004). Follett *et al*. (1987) found out that in one land use resource area in Minnesota an average SOC contents for soils on slope 0-2%, 3-5%, and 6-12% as 22.l, 13.5 and 8.9 g C/kg respectively. If environmental factors are similar, fine textured soils tend to accumulate higher amounts of organic C (Oades, 1995). Texture is particularly an important factor that influences the SOC storage capacity. It also affects drainage and aeration (Oades, 1995). Due to high moisture retention and relatively poor aeration of fine-textured soils, organic matter and nitrogen content are generally much higher in them than coarse-textured well drained soils. Generally, soil high in clay and silt are able to protect the protein nitrogen through organo-mineral complexes that are formed, which then result in high organic matter content of the soil (Nichols 1984; Burke *et al.*, 1989). Adsorption of various compounds

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by clays and sesquioxides generally serves to slow down their rate of decomposition. The organic matter held in the relatively stable pores in clay soils of diameter < 1µm is less accessible to microbial attack. Feller *et al.* (1991) have observed positive correlation between soil organic carbon and clay contents.

Mineralogy and soil texture has been known to affect the micro and macro structure of soils. Thus, organic matter is stabilized in the soil for a long time (Hassink *et al.,* 1997).

The organo-mineral complexation can be attributed to negative charges on the clay surfaces that enable an electrostatic binding to positively charged metal cations (e.g. $Ca^{2+,}$ Mg^{2+}).Thus, 2:1 clays (e.g. smectites), have more negative surface charge and more effectively stabilize organic matter compared to more low charged clay minerals such as 1:1 clays (Hassink *et al.,* 1997).

Soil management practices have been documented to have tremendous effects on SOC storage. In a study of adjacent forested and cultivated soils in eight agro ecosystems from Ethiopian highlands and Nigerian lowlands, Spaccini *et al.* (2001) observed that SOC content was two or four times higher in the forested soil than the cultivated. Bostick *et al.* (2006) also reported significant reductions from a continuous fallow of 0.53 % C to 0.46, 0.37, 0.35 and 0.33 % C for Sorghum-fallow, continuous cotton, continuous sorghum and cotton-maize sorghum rotations respectively, from an 11-year experiment to analyze SOC sequestration options in cropping systems in Burkina Faso.

2.4 Soil organic matter pools

Soil organic matter is not homogenous in composition. It consists of several different pools that vary in their intrinsic properties. Generally SOC fractions are described as either light or heavy (Lee *et al.,* 2009). The light fractions are discussed earlier under section 2.1 in this study constitute those turn over or decay rates ranging from months to 5 years. The heavy fractions are those with

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turnover times of decades to centuries (McGill, 1996). Researchers however prefer to employ the concept of carbon pools to distinguish the different cycling rates of SOC carbon in the ecosystem. Thus, in describing the dynamics of SOC, the general approach is to classify it into various pools. (Jackson *et al.*, 2002). As yet there is no general agreement on the number of pools of organic matter. However, for simplicity three (3) main pools may be recognized namely the (i) Active, (ii) Passive (intermediate) and (iii) Slow pool. Carbon in each pool has a different turnover time or Mean Residence Time (MRT). The active pool often has turnover rates of some few days to years whereas the passive pool has turnover rate of hundreds of years to centuries (Post *et al.*, 2001).The slow pool dynamics lies in-between. In scientific literature, especially those relating to soil fertility, the active pool is also often described as labile and the slow and passive pools combined into a non-labile resulting in a simple 2-pool description.

Due to the coarse-texture, high temperatures and adequate moisture of many sub humid and even semi-arid tropical soils, the labile pool decomposes rapidly once vegetation is cleared and the soil is disturbed by farming practices. In a 4- year rotation studies at Kpeve in Ghana, Adiku *et al*., (2009) found that SOC (in the 0-0.2 m layer) at the end of the trial was lower for all treatments than the initial value of 18.1 g/kg. The maize–bare fallow rotation lost almost 55% of SOC, while the maize–grass rotations with residue burning and residue incorporation maintained SOC near 12.0 g/kg, having lost about 34%. Among the maize–legume rotations, the maize–cowpea treatment had the highest SOC (12.2 g/kg), followed by the maize–pigeon pea rotation. The fertilized maize–grass rotation had the highest SOC (14.7 g/kg), losing only 19% by the end of the trial.

Carbon pools are not distinct groups of carbon compounds, but are fractions. There are two (2) soil fractions, the light fraction and the heavy fraction, which are further classified and range from free light fraction to the heavy occluded fraction. Light fractions also called the labile fractions

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are composed of fresh plant materials that are subject to rapid decomposition, with turnover from a few months to a few years. Early changes in SOC due to management often occur in the small light fraction, which is known for its spatial and temporal variability. Because most of turnover of SOM is in the light fractions, it is important to include this fraction within any chosen quantification methodology (Post *et al.*, 2001). Accumulation of light fraction carbon can be quite large in permanently vegetated soils (i.e. forest and grasslands). Carbon in the heavy occluded fraction has a Mean Residence Time (MRT) from hundreds to over a thousand years. Soil organic carbon and soil organic matter in this fraction are less susceptible to decomposition than in the light fraction. The heavy fraction is composed of polysaccharides (sugar) and humic materials often stabilized in complexes with clay minerals and silt-sized particles (Schlesinger, 1997). One very chemically recalcitrant portion of the heavy fraction has turnover times of 1,500 to 3,500 years (Post *et al*., 2001). In furtherance of the soil carbon pool and fraction concept, SOC and SOM can be protected from microbial metabolization or decomposition through three ways (Jastrow and Miller, 1998), (i) Biochemical recalcitrance occurs due to the chemical characteristics of carbon substrate and because substrates are not consumed by microbes, they remain un-decayed compounds and become progressively less decomposable. (ii) Chemical stabilization occurs with the bonding of positively charged cations associated with SOC to negatively charged ion and clay anions. (iii) Physical protection of SOM occurs within soil aggregates, held together by "aggregate glues" such as glomalin, a sticky substance produced by soil fungi that is 30 – 40% carbon by weight. Soil organic carbon lower in the profile tends to be protected from microbial decomposition due to chemical stabilization. Physical protection can vary by depth and soil type (Del Galdo *et al*., 2003).

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2.4.1 Methods of SOM Determination

Over the years, SOC is measured by wet or dry oxidation methods (Tiessen and Moir, 1993). Procedures for wet oxidation in acid dichromate solution are available either with or without external heating. In the later case, however, oxidation of organic carbon is incomplete. Thus only 74% of the SOM had been oxidized. A correction factor is therefore necessary if the total carbon is to be estimated (Walkey and Black, 1934). Tiessen and Moir (1993) suggested that as the recovery of carbon varies in an unknown manner; the wet oxidation method should only be used for treatment comparison but not across soil types. The complex nature of SOC makes its analysis to be done is several ways namely: physical fractionation methods, chemical fractionation methods and biological methods.

2.4.2 Physical Fractionation

Generally, organic matter is made up of material or particles of different sizes. It is known that those fractions that are made up of particulate organic matter fall within 53-2000 µm which comprises purely the sand fraction which is obtained purely by sieving (Gregorich and Ellert, 1993). Stevenson and Cole (1999) stated that the light fraction could also be separated by using both organic and inorganic liquid of density1.4 – 2.0 g/cm^3. It is observed that after sedimentation those particles that are not associated with soil minerals float on top of the liquid whiles those associated with minerals sink. In some cases, other researchers combine both approaches to separate the active fraction by using the coarse sand fraction instead of the whole soil for density separation (Barrios *et al.,* 1997). Anderson and Ingram (1993) noted that when combining different fractionation techniques there is a possibility of producing larger size of fractions which cannot be related to the pools of the whole soil.

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Some researchers have used wet sieving to separate aggregates and then dispersed the aggregates to quantify the free and the intra-aggregate particulate organic matter (Six *et al.*, 2000). In most cases, chemicals such as Sodium hexametaphosphate is used to effect dispersion of the particles with glass beads and ultra sound. In some cases however, sodic resins can be used. Six *et al.* (2000) established that some soils are difficult to disperse.

2.4.3 Chemical Methods

Over the years, chemical composition and transformation of carbon are studied using number of specialized techniques (Stevenson and Cole, 1999). Methods such as chromatography nuclear magnetic resonance spectroscopy and analytical pyrolysis were used to analyze the constituents of organic matter. Golchin *et al.* (1995) stated that their applications are complex and for that matter restricted to specialized laboratories. Blair *et al*. (1995) proposed an easier method by which labile carbon can be separated from the whole organic matter by selective oxidation. Loginow *et al.* (1987) was the first to propose the method where multiple concentration of $KMnO_4$were used to oxidize increasing proportion of soil carbon. Thus the amount of carbon oxidized by the chemical is a measure of its lability. The amount left unoxidised could be used to estimate stable non-labile fraction. Studies conducted by Lefroy *et al.* (1993) also showed that the use of a single dose of $KMnO_4$ at 333 mM sufficiently characterizes the labile carbon. The oxidizing agent was found to be more sensitive in measuring the labile fraction when 333 mM rather than 330 mM of the $KMnO_4$solution was used for detecting changes in the organic carbon of cultivated soils (Shang and Tiessen, 1997). Studies that have used multiple concentration of permanganate have consistently reported greater sensitivity to management with more dilute concentration (Weil, 2003; Vieira *et al.*, 2007). Weil (2003) further developed and streamlined this method by using lower concentration of $0.02 molL^{-1}$ $KMnO_4$ to measure the active C fraction of the total carbon. Idowu (2008) stated that the method is very rapid, inexpensive and can be

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modified for use in the field, and low-cost-fee for service soil testing for commercial growers. Other studies have found significantly positive relationship between Permangate oxidizable carbon (POXC) and microbial biomass (Jokela *et al.*, 2009; Culman *et al.*, 2010) which is also the measure of particulate organic carbon (POC).The $KMnO_4$ solution has been found to destroy respective fractions whiles the physical fractionation allows the further characterization of the isolated fractions.

Other separation technics are also available where organic matter is fractionated according to its solubility in acid and alkali to obtain fractions such as humic acids, fulvic acid and insoluble humin which had been found not to be closely related to soil organic matter function (Stevenson and Cole,1999).

2.4.4 Biological Methods

The decomposition and mineralization of organic matter is chiefly facilitated by the activities of microorganisms and the enzymes they produce (Swift *et al.*, 1979).The measurement of the population of the microbial community as well as the soil respiration is indicative of the type and amount of organic matter present (Gregorich *et al.*, 1994). Soil microbial biomass is an important component of soil quality assessment because of its important roles in nutrient dynamics, decomposition of natural and synthetic organic amendments (Smith and Paul, 1990).This has also been found to be directly related to the labile pool organic carbon (Jenkinson and Ladd, 1981). The microbial biomass accounts for only 1 - 3 % of soil organic C but it is the “eye of the needle” through which allorganic material that enters the soil must pass (Jenkinson, 1977). The most common methods utilized are variants of chloroform fumigation incubation (CFI) (Jenkinson and Powlson, 1976b), chloroform fumigation extraction (Vance *et al.*, 1987a), substrate-induced

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respiration (Anderson and Domsch, 1978) and adenosine triphosphate (ATP) (Webster *et al.*, 1984).

Soil respiration can be measured in the field or could be done under standardized conditions. However, there is growing concern that some of these methods may not be as reliable as others (Horwath *et al.,* 1996; Wu *et al.,* 1996), despite the intention of measuring the same pool. Soil respiration measurement provides an index of soil organic matter quality if the amount of carbon dioxide released is related to the total carbon present in the sample (Gregorich *et al.,* 1994). The fumigation-incubation method is the basic technique which is also used for calibration of the other methods. It is characterized by simple performance without the need for expensive equipment. Its application is limited to soils with a pH above 5 and to soils that do not contain easily degradable C sources. Under these conditions, negative microbial biomass estimates have been calculated as the control evolves more CO_2 than the fumigated sample (Smith *et al.,* 1995). If these limitations are not considered, too low or even negative biomass values will be obtained. These restrictions are largely overcome by the fumigation-extraction method.

2.5 SOM and soil productivity

Increasing the quantity of organic matter to the soil is known to improve soil physical properties such as its water holding capacity, tilth, reduces its bulk density thus increasing its infiltration and it is also known to affect its inherent mineral fertility (Duxbury *et al.,* 1989). This eventually culminates in the net productivity of the soil. Most of the nutrients in SOM are derived from the mineralization of SOM and become available for plant uptake during decomposition and for this reason; the particulate organic carbon is often considered the most important proportion of SOM in providing nutrients to plants (Wolf and Snyder, 2003). With the exception of fertilisers, SOM provides the largest pool of macro-nutrients with >95% of N and S and 20-75% of P found in

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SOM (Duxbury *et al.,* 1989; Baldock and Skjemstad, 2000). Additions of organic amendments have been shown to increase yields by increasing the nutrient status of the soil. Sustained nutrient availability may be compromised and crop yield can be depressed if immobilization of nutrients occurs during decomposition of the organic residues. Conversely, studies by Bowman *et al.* (1990) revealed nutrient losses in soil cultivated for 0, 3, 20 and 60 years. Total C, N and P declined by 55-63% over 60 years, with a corresponding decrease in yield. However more than half this decline occurred in the first three years of cropping indicating reduction in the labile pool as well as its association with the nutrient dynamics than the TOC. Building the labile carbon content of the soil is necessary for crop productivity and hence a measure of sustainability (Lefroy *et al.,* 1993)

2.6. Dynamics of Soil Carbon

Carbon sequestration is defined as the capture and secure storage of carbon in plants and soils that would otherwise be emitted to or remain in the atmosphere, (FAO, 2000). In the face of climate change and increasing CO_2 levels in the atmosphere, the global carbon cycle, soil organic carbon sequestration, and the role of different world biomes as potential sources and sinks of carbon are receiving increasing attention (Feller and Bernoux, 2008).Assessments of the potential of short term management systems to sequester C, based on the measurement of total amount of SOC and changes in total SOC with the management systems have proven futile. Jones *et al.* (2004) computed measurement standards errors of about 1000 kg $ha^{-1}yr^{-1}$. Pichot *et al*. (1981) observed that average soil carbon increased between 116 and 377 kg ha-1 yr-1 in a 10 year study in Burkina Faso for treatment with low and high levels of both inorganic and organic fertilizer respectively.

Levels of particulate organic carbon (POC) and or C from microbial population have been found to respond more quickly to changes in soil and crop management practices than total SOC

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(Magdoff and Weil, 2004). It is known that changes in organic matter over time or the turnover of SOC under different management practices can be expressed mathematically as follows.

Net organic C change = C_{gains} - C_{loss} [2.2]

Depending on the crop residue, soil, or organic matter management systems, the following four patterns of SOC changes would occur:

(i) C_{gains} exceed C_{loses}

When large quantities of crop residue or organic amendment are applied, and when annually soils are planted to perennial forage crops, a rapid increase in SOC occurs. Studies have shown that during this buildup of SOC, POC is a major fraction that increases whereas little or no new humus is added. Soil biology also undergoes dramatic shifts as activities of organism increase and population changes in relative abundance (Magdoff and Weil, 2004). This is an attribute of most forest soils.

(ii) C gains are less than C losses

Spaccini *et al.* (2001) have observed SOC losses when natural vegetation have been converted to agricultural lands. Changes in tillage practices influence mineralization by changing air and water relations in the soil. Tillage has been pointed out as one of the major factors responsible for decreasing carbon in agricultural soils. The mould board plough and disc harrow are the biggest contributors to the loss of soil carbon through their destruction of soil aggregates and acceleration of decomposition by mixing of plant residues, oxygen and microbial biomass (Pretty *et al.*, 2002). Soil aggregates are vital for carbon sequestration (Six *et al.,* 1999), a process that is maximal at intermediate aggregate turnover (Plante and McGill, 2002). Of the organic matter fraction, the

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particulate organic matter is the most tillage sensitive (Hussain *et al.*, 1999). For example, Rice *et al.* (1986) found that changing to no tillage system reduced the available nitrogen supply for a few years following the change; the reason is because conventional tillage aerates the soil and thus accelerates decomposition. Constantini *et al.*, (1996) also found that more CO2 was released from zero-till or reduced –till compared to conventional tillage despite increased levels of soil carbon. This was ascribed to an increase in the microbial biomass.

(iii) C_{gains} equal C_{losses}

When sufficient crop residues or organic amendments are applied to offset SOC losses under cultivation, the total soil organic matter will remain unchanged. Magdoff and Amadon (1980) reported that 20 % loss of SOM over a 5 year period occurred for corn silage on clay soil under conventional tillage with no added manure. But application of 44 Mg/ha diary manure (fresh weight) maintained SOM at the original level of 52 g/kg.

(v) C_{gains} and C_{losses} fluctuate cyclically

Fields that are in rotations with low-residue crops for a few years alternating with high-residue crops, or intensively tilled crops alternating with no tillage with perennial forages will have SOM alternating between decreasing and increasing phases (Magdoff and Weil, 2004)

2.7 Carbon Sequestration and climate change

According to White, (1987) SOC turnover is referred to as organic matter accumulated in the soil through residue decomposition and root death which are often offset by leaching erosion and carbon mineralization. Carbon sequestration in plant and soil systems offers an opportunity for mitigating the greenhouse effect as well as improving soil fertility (Lal, 2004). In soil systems

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effective and efficient management of the soil carbon store-house is thus essential for maintaining soil fertility and sustaining high yields.

Land misuse and soil mismanagement, however, have caused depletion of soil organic carbon with an immediate release of CO_2 and other greenhouse gas into the atmosphere. This presupposes, therefore, that enhancing SOC pool could substantially offset CO_2 emissions as well as sequester carbon for crop production (Kauppi *et al.*, 2001). However, SOC sink capacity depends on the antecedent level of soil organic matter (SOM), management, and climate and soil profile characteristics.

Lal *et al.* (2001) and Reicosky *et al.* (2000) reported that carbon dioxide present in the atmosphere is between 720 and 750 Gt, and between 550 and 835 Gt in plant biomass. In Ghana for instance, EPA (2000) has indicated that over the past thirty (30) years, the average temperatures of most places have increased by 1°C and the average precipitation reduced by 1 % in most areas. Soils however, contained between 1200 and 2200 Gt of C, with soils in dry regions containing an additional 700 to 946 Gt (10^9 kg) of C as carbonates in petrocalcic horizons.

Paustian, (1998b) asserted that soils globally have the potential to store 20 to 330 Pg (10^{15} kg) of C in the next 50 to 100 years at an approximate rate of 0.4-0.9 Pg (10^{15} kg) C/year. This represents 6 to 10 % of current C emission from fossil fuels combustion. These values take into consideration the restoration of degraded soils and ecosystems as well as the conversion of marginal agricultural soils to perennial vegetation and the adoption of recommended management practices on agriculture soils. These include reduced tillage, mulching, residue incorporation; cover cropping, crop rotation, integrated nutrient and pest management.

The release of CO_2 from soil (soil CO_2 efflux or soil respiration) has been found to be the largest source of carbon to the atmosphere in most terrestrial ecosystems (Schlesinger and Andrews,

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2000). Anthropogenic activities such as agriculture have been identified among the major causes for the increase of these GHG's namely Carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Whereas much of the historical emissions of GHGs may be attributed to fossil fuel burning, land use change accounts for recent increases in emissions from fertilizer application, rice fields, domestic animals and biomass burning. Thus the implementation of reduced tillage, cover cropping as well as residue incorporation will lead to accumulation of organic matter in the soil thereby improving soil quality and soil CO2 efflux (Lal, 2004a).

2.8 Managing SOM

Soil organic carbon accumulation is determined by the net balance between inputs and SOC outputs. SOC inputs and output are affected by management and by two biotic processes (production of organic matter in the soil and decomposition of organic matter by microorganisms) (Jones, 2007 and Svecjcar *et al.*, 2008). Soil organic matter decomposition is the product of on-site decomposition and it affects the chemical and physical properties of the soil and its overall health. Its composition affects the porosity, water infiltration rate moisture holding capacity and soil structure. Collins *et al.* (1997) observed that it has effect on the diversity as well as the biological activity of the soil microorganism and consequently on the plant nutrient availability. It is known to comprise carbon-rich organic materials derived from animal and plant residues that have undergone decomposition by microorganisms to varying degrees. Organic carbon comprises about 48 to 58% of SOM mass as a result SOM values are usually derived from the measurement of SOC.

Many researchers have observed that significant losses of SOM have resulted from intensive cultivation of native soils (Nye and Greenland, 1960, Spaccini *et al*, 2001; Bostic., 2006; Poeplau *et al.*, 2011).

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Duxbury *et al.* (1989) have noted that when fallow land is converted to agriculture it renders the SOM protected fraction to mineralization. This results in the disruption in the internal cycling of nutrients, thus increasing the potential for nutrient and carbon loss. Spaccini *et al*. (2001) has noted that agricultural practices, particularly tillage accelerate the loss of C from the soil by erosion and respiration. Thus, tillage is one management practice that influences SOM accumulation.

Conversely, Zhang *et al.* (2006) observed that forest soils showed 6 and 8% more TOC than crop and tree plantation soils respectively. Improved pasture and urban soils were found to contain 8 and 12% more TOC than tree plantation soils (Cohen *et al.*, 2008). Cultivation, therefore, leads to decreased stocks of SOM. Searchinger *et al.* (2008) also observed cultivation can modify long-term soil C stocks by ±50%. Some of the greatest soil C losses that accompany a landuse change have been observed during the transition from forest or pasture to annual crops, with the largest C increases attending the converse land use transformations (Guo and Gifford, 2002). However, various conservation practices exist that can be utilized to increase SOC storage as well as improve quality in agricultural soils. These include reduced tillage, crop rotations, organic amendment, agroforestry (Sbih, 2003), mixed cropping and cover cropping.

2.8.1 Tillage

Soil tillage is an ancient practice that is still used in modern agriculture for the controlling of weeds as well as preparing good quality seed bed (Jones *et al.*, 1990). It improves soil physical conditions by loosening compacted soils enhancing warming and ease the incorporation of fertilizer, herbicides and plant residues in the soil (Lal, 2001). It is one of the management practices that influences the losses of SOC from most soils. Firstly as the soil is disturbed most of the soil aggregates are disrupted as well as releasing previously protected organic carbon to

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become available to micro flora. This leads to rapid decomposition of crop residues as the soil maintains conditions of moisture, nitrogen availability and suitable temperature for microbial decomposition (Wilson and Al-Kaisi, 2008). Also diverse population of soil decomposers is now in direct contact with the residues tilled in the soil.

Curtin *et al.* (2000) provided evidence in his investigations that less intense tillage, especially no till increases SOC accumulation by reducing organic matter losses in the surface layers. In this study wheat fallow under conventional tillage and no till management were compared and the results showed that surface residues accounted for additional carbon sequested in no till compared to conventional tillage. Similar observations were made by Dick *et al.* (1991) who reported changes in SOC under no till during the first 10 years of a 25 year experiment.

2.8.2 Cropping practices

It is the practice of growing a sequence of different crops on the same piece of land. The fundamental influence of crop rotations on SOC storage may be related to the amount of crop residues returned to the soil. Crop residues being the primary source of SOM, means that utilizing crops that increase residue return to the soil in given rotation has the potential to maintain or increase SOC pool. Several studies have reported changes in SOC proportional to the amount of residues returned to the soil by various crop rotations. Campbell and Zentner, (1993) found a direct positive relationship between the quantity of crop residue and its N content to SOM after 24 years of a crop rotation experiment. In an 11 year experiment to analyze SOC sequestration options in cropping systems in Burkina Faso, Bostick *et al.* (2006) reported significant reduction of SOC from the continuous fallow of 0.53 % C to 0.4,0.73,0.35 and 0.33% for Sorghum fallow, continuous cotton, continuous sorghum and cotton –maize-sorghum rotation respectively

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2.8.3 Organic and fertilizer (inorganic) amendments

Different organic materials each with unique characteristics have different effects on soil biological chemical or physical properties. Thus one of the strategies of SOM management is to use a variety of organic materials (Madoff and Weil, 2004). Different types of residues remain in the field when crop rotations or crop residues are used. On the other hand, different organic amendments can be brought from off the field including various types of animal manures, crop residues, grass clippings, food processing waste, and sewage sludge. A study conducted by Pausian *et al.* (2000) showed that the quantity and the composition of organic matter influence organic carbon accumulation. He stated that when 250 and 500 g of organic material/m^2/year was added to moderately coarse textured soils in Canada and Sweden, SOM increased in the order, alfalfa-straw-animal manure. They explained that animal manure consist of relatively recalcitrant compounds, the mostly oxidized compounds in the original plant tissue having been broken by the digestive system before the excretion of the manure. Animal manure additions have been known to impact on SOC many years after additions have ceased (Jenkinson and Johnson, 1977). Thus it increases the stable organic matter pool.

Conversely, long term studies have shown that fertilizer additions increase the amount of organic matter in the soil by boosting the production of biomass which after incorporation in the soil elevates organic carbon levels (Paustian *et al.,* 1997). Fertilization is a primary means used to increase plant productivity and crop yield. Any increase in biomass also offers increased scope for carbon sequestration by soil. Himes (1998) estimated that it takes 833 kg N, 200 kg P and 143 kg S to sequester 10 tonnes of carbon in humus. Soil fertility is therefore an important aspect of carbon sequestration. Fertilization has been recommended and proven to be successful method of increasing carbon sequestration (Lal *et al.,* 1999). A few field experiments suggest that soil organic matter increases with elevated CO_2 (Schlesinger, 1977). Large accumulations of organic

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matter are expected where environmental factors (e.g. temperature) limit decomposers. Thus, increased delivery of labile organic matter to the soil could influence soil microbial communities and furthermore soil respiration rates. Liebig *et al.* (2002) also reported that nitrogen fertilization was found to have a greater impact on organic matter than non-fertilized crop residues. This is as a result of the fact that organic matter concentration in the soil depends both on the quantity and quality of the residues applied. Furthermore, studies have however shown that additions of mineral fertilizers and manures helped maintain organic matter levels but could not negate declines caused by tillage over a 20-year period.

2.8.4 Soil Carbon Management Index (CMI)

Carbon management is an index that is used to assess the capacity of soil management systems to promote soil quality (Viera, 2007). Blair, (1995) first defined CMI. Though a fixed value was not given to this index, it has however been assumed that the state of a natural system is 100 which is often used for reference soil. With this assumption, it is possible to estimate whether the CMI is either low or high for particular management practice (Viera, 2007). Bona *et al.* (2008) indicated that values below or above 100 indicate either a negative or positive impact on TOC content and soil quality respectively. CMI is known to be associated with SOC pools. Xu *et al.* (2008) also confirms that CMI reflect the changes in labile organic carbon and thus can be used to assess the capacity of management systems to promote soil quality.

Recent studies by Blair *et al.* (2006) stated that CMI can be used as a more sensitive indicator of the changes in SOC in response to land management changes. The relationship between CMI and SOC pools suggest that management practices that enhance SOC build up improves CMI. To this end Whitbread *et al*. (1998) suggested CMI to be a useful technique for describing soil fertility. A study conducted by Tirol-Padre and Ladha, (2004), reveals that CMI was more significantly

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enhanced by the organic manure treatments than Nitrogen treatment. This is due to the increase in annual C input and the variations in organic matter quality, thus modifying the liability of C to $KMnO_4$ oxidation. The result was later confirmed by Blair *et al*. (2006) who reported that manure and manure with inorganic fertilizer significantly increased CMI compared to any other chemical fertilizer treatments in a long-term experiment.

Investigations conducted by Gong *et al*. (2009) also revealed that 18 years of organic manure addition (alone and in combination with N fertilizer) was more effective for increasing CMI than chemical fertilizer alone in a wheat–maize system. The significant correlation between CMI and each of the C fractions strengthen the suitability of using $KMnO_4$-C for calculating CMI and the reliability of CMI as an indicator for evaluating SOC change. CMI is the product of carbon pool index (CPI) and the Lability Index (LI). Any change in TOC pool size as affected by land use is expressed using the carbon pool index (CPI), which is calculated from sample total C (TOC in the cultivated soil) expressed as a fraction of the reference total C (TOC in the native forest soil) (Blair *et al.,* 1995). Lower CPI values indicate higher organic C loss. CPI > 1 also indicates aggradation in soil quality as related to soil organic matter content and to all benefits of this component for soil improvement while the lability index is expressed as the lability of cultivated soil with respect to that of the native soil. It is known to increase with depth (Danielle *et al*., 2014). Lability is the measure of the nutrient dynamics and sustainability (Lefroy,1993)

2.8.5 Agroforestry

This refers to land use system in which woody perennials (trees, shrubs) are grown in association with herbaceous plants (crops and pastures) and livestock in a spatial arrangement, a rotation or both and in which there are both ecological and economic interaction between the tree and the non-tree component of the system (Young, 1991). Agroforestry is among the methods proposed

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for the improvement and the maintenance of soil quality of traditional agriculture systems and pastures that contain more biomass carbon than the crop land. On a Vertisol in Ethiopia, Lulu and Insam (2000) observed positive effects of agroforestry practice with Sesbania on SOC pool.

2.8.6 Cover Crops

Another way to increase the amount of crop residue carbon added to the soil is through the use of cover crops to fill the seasonal niches when commercial crops are not growing (Madoff and Weil 2004). Growing cover crops in rotation cycles accentuates the benefits of adopting no till for SOC sequestration. Sainju *et al.* (2002) reported that practicing no till with hairy vetch can improve SOC levels. He also further reported that growing leguminous cover crops enhances biodiversity, the quality of residue input and the SOC pool. Drinkwater *et al*. (1998) observed that leguminous based cropping system reduced Carbon and Nitrogen losses from the soil.

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CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Location and physiography of Area.

This study was conducted within the Tolon-Kunbungu and Savelugu-Nanton Districts of Tamale, in the Northern region of Ghana, located within (09.40307N, 000.96162W) and (09.58652N, 000.87584W), (Fig 3.1). The location falls within the Guinea savannah Agro-ecological zone of Ghana. The zone experiences a mono-modal rainfall pattern of about 5 to 6 months yearly beginning from May to October, with a long term annual mean precipitation of 1120mm. Mean annual temperatures are generally high with maximum and minimum of 34.3 and 23.4 ^{o}C respectively. During the dry season (November to April), the area is under the influence of the North-East Trade Winds (Harmattan) and as a result relative humidity declines to about 16 % in January and then rises to about 70 % in August during the wet season.

The soils from Dimabi and Nyankpala have been classified as Plinthic Lixisols by FAO, (2001). They are derived from bongo granite and associated basic rocks (Brash, 1962).They are shallow, sandy loam in texture, having medium and coarse quartz stones and iron pan boulders often appearing on the surface. Crops mostly cultivated in the area are cereals (maize, sorghum and millet) and legumes (groundnut, cowpea, and soybean).

Continuous cropping, slash and burn or shifting cultivation and mixed farming involving crops and small ruminants (e.g. goats, pigs and sheep), and large ruminants (cattle) production are the predominant agricultural systems typical of the study area.

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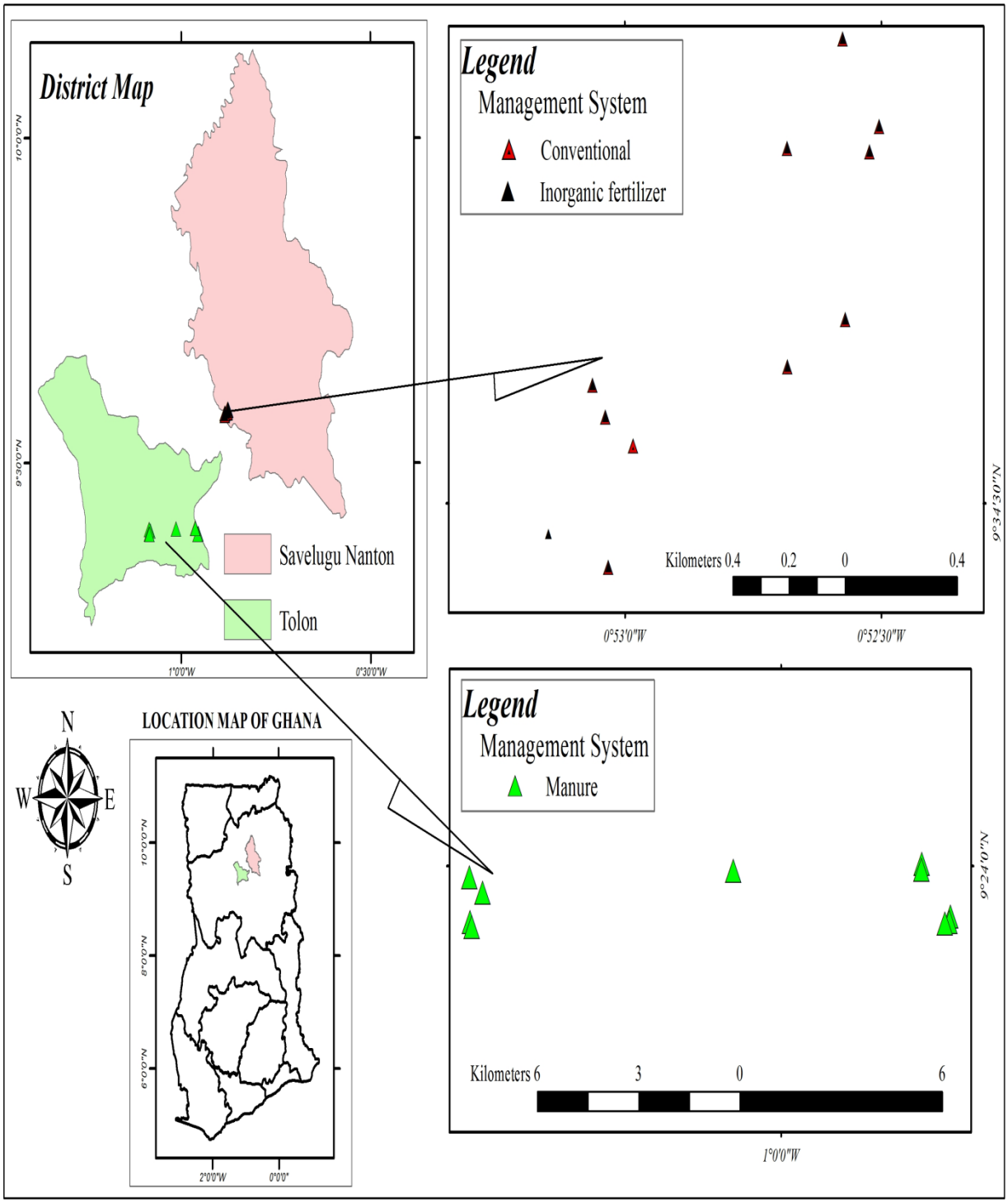

Fig. 3 1 Ghana map showing project locations

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3.2 Data Collection

3.2.1 Field Survey

The study was conducted from June to October 2014 at three sites on farmers' field in the Northern Region of Ghana. Unlike the conventional experimental approach the different farmers were considered as replicates in space of treatment. The treatment were:

(vi) Manure

(vii) Fertilizer application

(viii) No manure or fertilizer application

For the period in question maize was grown by the farmers. A total 10 farmers were selected for each category at each site. Thus in total, there were 3x 3 x 10 observation units. Since no designed management was composed in this study, farmers' management was accepted as treatment levels. Farmers at Dimabi planted the Obatanpa maize variety. Planting was done during the fourth week of June 2014.Those who applied manure used cattle dung, animal dropping and crop residues as the source and applied approximately 1000 kg/ha. Farmers at Nyankpala, using manure to fertilize their crops also used the same rate.

Also, Farmers at Savelugu are those who applied chemical fertilizers used NPK compound as the source of Nitrogen at the rate of 37.5 kg/ha. Another group of farmers at Savelugu neither apply chemical fertilizers nor manure.

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3.2.2 Soil sampling and analysis

Soils were sampled from 0-10 and 10 -20 cm from each farmers field in each management category. In addition to this, soils were also sampled from a long term fallowed field near the farm to serve as control. The soils were air-dried and passed through 2mm sieve mesh and stored for texture, pH, SOC and SOC fractions (pools) determinations.

3.2.2.1 Particle size distribution.

The particle size analysis was done using the hydrometer method as outlined by Bouyoucos (1951). A 40 g of fine earth sample was weighed into the extraction bottle. One hundred (100 ml) of 5% sodium hexametaphosphate (calgon) was dispensed onto the soil samples and tightly closed. Samples were placed inside the mechanical shaker to shake for two hours at 200 revolutions per minute. The suspensions are transferred into 1000ml sedimentation cylinders and topped up with distilled to the 1000^{th} mark. A hydrometer was used to measure the density of the suspension at 40s after mixing vigorously with a plunger. The hydrometer reading was taken again after 5 hours without any agitation. The sand fraction was recovered by decantation and the dry weight recorded after it had been oven dried for 2 days at 105^{o}C and cooled in desiccator. The clay and silt fractions were determined by the difference in the 5 minutes and 5 hour readings. The percentage clay and silt were estimated using the relation below.

The textural class of the sand, silt and clay were determined using the USDA textural triangle.

$$\%(\text{Clay} + \text{Silt}) = \frac{\text{Hydrometer reading at 5mins}}{\text{weight of soil (g)}} \times 100 \qquad [3.1]$$

$$\text{Clay}\ (\%) = \frac{\text{Hydrometer reading at 5 hours}}{\text{weight of soil (g)}} \times 100 \qquad [3.2]$$

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$$\text{Silt (\%)} = [\%\text{Clay} + \text{Silt}] - \text{Clay (\%)} \quad [3.3]$$

$$\text{Sand (\%)} = \frac{\text{Weight of oven dry sand retained on the 47µm seive}}{\text{weight of soil (g)}} \times 100 \quad [3.4$$

3.2.2.2 Soil bulk Density

Core samplers of both 5cm internal diameter and height were used to take samples for bulk density determinations. The sampler was driven into the soil with the aid of a second core placed on top of the first core and hammered into the soil till the first core is completely buried. The first sampler was dug out and trimmed at both ends. Extraneous soils at both sides were removed. The soil sample was then pushed out into a moisture can and oven-dried at 105 ºC for 48 hours. The bulk density of the soil was calculated by dividing the oven dried soil weight by the volume of the core sampler.

$$\rho b = \frac{\text{weight of oven dry soil}}{\text{volume of soil}} \quad [3.5]$$

3.2.2.3 Soil pH

Soil pH was measured in 1:1 (soil: water) suspension using the electrode MV88 Praitronic pH meter. A 20 g soil sample was weighed in a 50 ml beaker and 20 ml of distilled water was added. The mixture was stirred with a glass rod for 30 minutes and allowed to sand for 1 hour. The pH of the suspension was read on the electronic pH meter. Prior to reading of samples, the pH meter was standardized with buffer solutions of pH 4 and pH 7.

3.2.2.4 Exchangeable Bases

Ten gram soil was weighed into an extraction bottle and 100 ml of 1N ammonium acetate solution of pH 7.0 was added. The mixture was shaken for one hour after which the content was filtered

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with Whatman No 42 filter paper. Aliquot of the extract were used for the determination of Ca^{2+},$Mg^{2+,}$ K^{+} and Na^{+}. Exchangeable Na and K were determined using the flame photometer by calibrating the photometer with standard 10 ppm of Na and K solutions and reading the Na and K concentrations of the extracts.

3.3 Organic carbon and carbon fractions

3.3.1 Total carbon

The Walkey-Black method as modified by Allison (1965) was used to determine the total soil organic carbon content. Ten ml of 1N Potassium dichromate and 20 ml of concentrated (98 %) sulphuric acid (H_2SO_4) were added to a 0.5 g soil in an Erlenmeyer flask. The flask was swirled and allowed to stand for 30 minutes and 200 ml of distilled water was added mixed and allowed to cool. The residual of the dichromate remaining in solution after the oxidation of the oxidizable organic material in the soil sample was titrated against 0.2 N ammonium ferrous sulphate solution after 10ml of 85% Orthophosphoric acid and 1ml indicator solution (barium diphenylamine sulphate) were added and titrated to a green end point. A blank in which the same procedure was followed but without any soil sample was used as a check. The carbon content was calculated as follows.

$$\% \text{ SOC } = \frac{[10 - \text{XN}] \times 0.3 \times 1.333}{\text{sample weight}} \qquad [3.6]$$

X = volume of ammonium ferrous sulphate solution titrated,

N = Normality of ferrous ammonium sulphate (10/volume of ammonium sulphate titrated with the blank.

W =weight of soil samples taken, 0.3 = milliequivalent of carbon

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1.33 = correction factor Walkley and Black assuming an average 77% recovery of organic carbon by this method

3.3.1Total nitrogen

The Kjeldhal method (Hesse, 1971) was used to determine total nitrogen. A 2.0 g soil sample was put into a micro Kjeldahl flask and 1.0 g of digestor accelerator (10 g of K_2SO_4 + 1.0 g $CuSO_4.5H_2O$ 0.1 g Selenium) was added. About 1 ml distilled water was added to moisten the soil and 5 ml concentrated sulphuric acid was also added. The flask was put on the digestor and the mixture was allowed to digest for at least two hours until the digest became clear. It was then allowed to cool and then transferred with distilled water into a 50 ml and made volumetric flask and up to the volume. A 5 ml aliquot was put into a Markham distilled apparatus and 5 ml of 40% NaOH was added and distilled.

The distillate was collected into 5 ml of 2% boric acid to which about three drops of a mixture of methyl red and methylene blue indicator solution were added. The distillate was titrated with 0.01N HCl from green to an indicator reddish end point. Total Nitrogen was calculated using:

$$\%\text{Nitrogen} = \frac{N \times X \times 50 \times 0.014}{W \times V} \times 100 \qquad [3.7]$$

Where;

N=Normality of HCl used (N)

X= Volume of HCl used for titration (ml)

V=volume of filtrate (aliquot used for the distillation, ml)

W= Weight of soil for the digestion (g)

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3.3.2. Available phosphorus

Available phosphorus was determined by the Bray 1 method. A 5 g soil sample was weight into the extraction bottle and 25 ml of Bray1(0.03M NH_4F and 0.025M HCl) solution was dispensed onto it. The mixture was shaken for 3 minutes on a reciprocal shaker and immediately filtered through Whatman No 42 filter after shaking. Standard solution of 0, 1, 3, and 5 mg P/L were prepared by pipetting respectively, 0,5,15 and 25 ml of 20 mg P/L solution into the labeled 100 ml volumetric flask and of Bray 1 solution added as in the soil samples topping up the mark with distilled water. A blue colored solution was developed, and standard series were prepared by the addition of Ammonium Molybdate and ascorbic acid. A blank solution containing all the reagents except the sample was used to calibrate the spectrophotometer in addition to the standards. The concentration of P was measured using a UV-Spectrophotometer at a wavelength of 712 nm.

$$P\ (mg/kg) = \frac{\text{Spectrometer reading (R)} \times \text{Volume of extract}}{\text{aliquot x weight of soil sample}} \qquad [3.8]$$

3.3.3 Measurement of Carbon fractions

Several SOC fractions were determined in this study. First, OC associated with the various soil separates (sand, silt and clay) were determined using the Walkley-Black procedure. A known weight of the fractions was taken into a conical flask and the Walkley and Black procedure was followed to determine the total carbon.

3.3.4 Permanganate Oxidizable Carbon, POXC (labile carbon)

The second fractionation approach was to determine the labile SOC which was assumed to be the same as the POXC. The procedure determination is detailed by Viera *et al.* (2007). For this, exactly 1.0 g of the soil sample that had been passed through 2 mm sieve was weighed into an

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extraction bottle and 25 ml of 0.001332M of $KMnO_4$ was dispensed into it and closed tightly. The samples are shaken in the mechanical shaker for 30 minutes. The samples were filtered through Whatman No 42 filter paper. The filtrate was further diluted 250 times and its absorbance using a spectrophotometer at a wavelength of 565 nm determined. The absorbance of five other standards of the concentrations, 0.000270 M, 0.00285 M., 0.000300 M, 0.000315 M and 0.000330 M were also recorded and standard curve drawn. The labile SOC was also determined in the soil separates (sand, silt and clay). Reading was done on the spectrophotometer at the same wavelength as above.

The Permanganate Oxidizable Carbon (labile carbon) was determined as follows:

$$\text{POXC (mg/kg soil)} = [1.332 \times 10^{-3} mol\ L^{-1} - (\text{a} + \text{b} \times \text{Abs})] \times (9000\ mg\ C\ mol^{-1})(0.333\ \text{L solution/weight}) \quad [3.9]$$

Other SOC quality indices were determined as follows:

$$CMI = CPI \times LI \times 100 \quad [3.10]$$

$$\text{Carbon Pool Index (CPI)} = \frac{\%\ \text{carbon of sample}}{\%\ \text{carbon of virgin land}} \quad [3.11]$$

$$\text{Lability Index (LI)} = \frac{\text{Labile carbon of sample}}{\text{Labile carbon of virgin land}} \quad [3.12]$$

3.4 Statistical analysis

Microsoft excel was used for data entry, while simple and multiple regression analysis were used to determine the relationship among the various management practices and maize yield, organic matter pools. All analyses were performed on data collected on soils before and at the end of the

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cropping season. Analysis of variance was carried out to assess the significance differences among practices in terms of labile C.

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CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Soil characterization

Tables 4.1 and 4.2 summarize information on the physical and chemical characteristics of the farmers' field prior to the commencement of, and at the end of the study. The soils of Nyankpala and Dimabi were sandy loam in nature whiles that of Savelugu was loamy sand. The sand content of Savelugu is very high (74.11%) and that of clay and silt are (23.01%) and (2.88%) respectively.

The soil pH can be described as weakly acidic with pH values of 6.1 in soils from Savelugu while that of Dimabi and Nyankpala were 6.8 and 6.4 respectively. The soil from Dimabi can be described as neutral as its pH value is approximately 7. Organic carbon content was relatively low (0.2%) in the soils of Savelugu with no fertilizer management. The organic carbon content of Dimabi and Nyankpala soils were relatively higher with values of 0.50% and 0.56% respectively (Table 4.1a). The generally low organic carbon values may be due to rapid mineralization of organic matter overtime due to the high temperatures that characterize the area. Total nitrogen values were characteristically low (0.07%) with highest value occurring in the organic manure managed soils at Dimabi (Table 4.1a). This may be attributed to poor recycling of organic matter in the area worsened by frequent bush fires. The low carbon content of the soils is characteristic of soils in the semi–arid ecosystems where the high rate of mineralization due to high temperatures reduces the accumulation of carbon (Dowuona *et al* 2012). Consequently the organic matter contents of the soils are low. Soil nitrogen measurements were compared to broad ratings described by Landon (1984) as very high (>10 g/kg), high (5–10 g/kg), medium (2−5 g/kg), low (1−2 g/ kg) and very low (<1 g/ kg). Based on this, the results showed generally very low nitrogen contents of the soils (Table 4.1).

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The C/N ratio is an index of soil quality and used in predicting the rate of decomposition (Heal *et al.*, 1997). The low C/N ratio of the soils confirms the high rate of decomposition of organic matter in the region.

Potassium values were also generally low with the highest value of 0.23 cmol/kg occurring in inorganic fertilizer amended soils at Savelugu (Table 4.1a). A gradual decline to 0.21 cmol/kg was observed in the soil after harvest as seen in (Table 4.1b). This could also be attributed to potassium uptake by the plants during the growing season.

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Table 4.1a: Some chemical and physical properties of the soil at the experimental site before planting.

Site	Management	Soil pH		SOC	Particle size (%)				TN	C/N	Exch. K
		(1:1 H_2O)	(KCl)	(g/kg)	Sand	Silt	Clay	Textural class	(mg/kg)		(cmol(+)/kg)
Dimabi	Manure	6.8	6.5	5.6	62.73	33.83	3.44	SL	0.07	8.0	0.22
Nyankpala	Manure	6.4	6.1	5.0	52.09	44.79	3.10	SL	0.05	10	0.21
Savelugu	Fertilised	6.1	5.8	3.9	74.11	23.01	2.88	LS	0.05	7.8	0.23
Savelugu	Non-fertilised	6.2	5.8	2.0	76.62	20.38	3.00	LS	0.05	4.0	0.21

***SL=Sandy Loam, LS=Loamy Sand, TN=Total nitrogen, Exch. K= Exchangeable Potassium.**

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Table 4.1b: Some chemical and physical properties of the soil at the experimental site after harvest.

Site	Management	Soil pH		SOC	Particle size (%)				TN	C/N	Exch. K
		(1:1 H_2O)	(KCl)	(g/kg)	Sand	Silt	Clay	Textural class	(mg/kg)		(cmol(+)/kg)
Dimabi	Manure	7.1	6.8	5.8	62.73	35.83	3.44	SL	0.023	25.2	0.170
Nyankpala	Manure	6.4	6.1	5.5	52.09	44.79	3.10	SL	0.026	25.1	0.13
Savelugu	Fertilised	6.1	5.8	4.9	74.11	23.01	2.88	LS	0.0217	22.3	0.19
Savelugu	Non-fertilised	6.1	5.7	4.4	76.62	20.38	3.00	LS	0.0224	20.0	0.

***SL=Sandy Loam LS=Loamy**

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4.2 The effects of soil management on organic carbon in soil fractions

Table 4.2a and 4.2b show the effects of concentration of SOC in the various soil separates. Also, Tables 4.2c and 4.2d show the proportion of organic carbon associated with the original soil separates. Carbon content increased as particle size decreased. This agrees with the findings of Chivenge *et al. (*2001) that finer particle size are able to hold more carbon due to their surface area. Soils from Dimabi manure farm had relatively higher OC content compared with the other management systems apparently due to manure application. Organic carbon in soils from Dimabi had the highest organic carbon of 5.84 g/kg, whereas, that of Nyankpala was 5.0g/kg The OC content in Savelugu soils was generally low (3.89 g/kg and 2.93 g/kg respectively). High OC in the fractions under organic manure managed systems compared with those of fertilized and non–fertilized management could be attributed to the additions of animal manure and compost which are known to increase the organic carbon content of soils (de Ridder and Keulen, 1990). It is also observed in both (Table 4.1a and b) that the organic carbon content in (table 4.1a) fallow, was lower than that of those in (table 4.1b).This also agrees with the observations of (Palm *et al.,* 2001) that when the soil is left fallow following bush burning, increased wetting and drying cycles could increase mineralization rates which leads to the loss of organic carbon. Studies conducted by Szott *et al*. (1999) also confirm that organic carbon could reduce during fallow periods depending upon the management that ensued even though it is known that leaving land fallow allow the land to regain its fertility.

Vanlauwe *et al*. (2001) reported that soils from West African savannah zone with fertilizer applications sequester more carbon slightly higher than those of non-fertilized soils. This is very much evident in the trend obtained in soils from the Savelugu fertilized and non-fertilized managements.

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Even though the concentration of C in clay was highest followed by that in silt and sand, the proportion of clay in the study area is very low, hence its contribution to soil fertility is very marginal. Given that the soil in the study area are sandy in nature, the largest proportion of the total organic carbon of the soil are associated with the sand separate (Table 4.2c and d).

The proportion of OC associated to the sand fractions was relatively high for (manured) soils at Dimabi before and after cultivation compared with other sites. Clay–C content was generally low prior to and after cultivation and this could be due to the low proportion of clay in the soil samples. The silt fractions for all the soils were also generally low except for Nyankpala where the organic OC in the silt was 0.23%. This could be due to the high proportion of silt in the soil. The clay fractions in all management systems across sites showed the lowest OC compared to the other fractions. However, organic manured soils at Dimabi showed the highest clay-C (1.18g/kg) compared to the clay-C from the other sites.

The sum of the organic carbon in the soil separate compare well with that of the whole soil, suggesting that the fractionation method used adequately captured carbon in the various soil separates.

The marginal differences may be attributed to measurement errors. The OC content of the manured fields (Tables 4.2a and b) was expected to be higher than the fertilized and the non-fertilized fields because of the additions of the organic residues to the soil (de Ridder and Keulen, 1990).

The OC concentration in all three soil separates for the unfertilized soils were significantly lower than that of the manured soil in Dimabi (Table 4.2a) before cultivation.

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Table 4.2a: Concentration of organic carbon in the various soils separates prior to cultivation.

Site	Management	(Sand C)	(Silt C)	(Clay C)
		g/kg		
Dimabi	Manure	4.04	5.08	28.00
Nyankpala	Manure	4.41	3.93	24.60
Savelugu	Fertilised	3.88	4.39	22.66
Savelugu	Non-fertilised	1.80	3.77	21.33

***fractional carbon values were obtained by multiplying soil carbon values with their fractions constituting the texture.**

Table 4.2b: Concentration of organic carbon in the various soils separates after harvest.

Site	Management	(Sand C)	(Silt C)	Clay C
		g/kg		
Dimabi	Manure	4.31	5.64	27.33
Nyankpala	Manure	4.97	4.71	29.25
Savelugu	Fertilised	3.12	6.63	27.66
Savelugu	Non-fertilised	2.48	5.35	21.60

***fractional carbon values were obtained by mulitplying soil carbon values with their fractions consistuting the textural percentages.**

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Table 4.2c.Soil organic carbon content of various soil fractions under different nutrient management prior to cultivation

Site	Management Practice	Soil Carbon Pool (g/kg)					
		Sand-C	Silt-C	Clay-C	Sum-C Fraction	Total soil C	Difference
Dimabi	**Manure**	2.54±0.10	1.71±0.05	0.96±0.04	5.21±0.13	5.84±0.16	0.63
Nyankpala	**Manure**	2.30±0.96	1.76±0.09	0.77±0.03	4.83±0.12	5.02±0.12	0.19
Savelugu	**Fertilized**	1.93±0.10	1.07±0.05	0.68±0.03	3.68±0.13	3.88±0.14	0.20
Savelugu	**Non-fertilizer**	1.38±0.07	0.77±0.28	0.64±0.02	2.79±0.08	2.93±0.08	0.14

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Table 4.2d. Soil organic carbon content of various soil fractions under different nutrient management after cultivation.

Site	Management Practice	Soil Carbon Pool (g/kg)					
		Sand-C	Silt-C	Clay-C	Sum-C	Total Soil C	Difference
(Dimabi)	Manure	2.60±0.13	1.91±0.05	1.11±0.04	5.62±0.13	5.98±0.16	0.11
Nyankpala	Manure	2.55±0.07	2.10±0.08	1.22±0.04	5.87±0.10	6.51±0.12	0.64
Savelugu	Fertilized	2.36±0.09	1.43 ±0.04	0.83±0.02	4.62±0.12	4.81±0.11	0.49
Savelugu	Non-fertilizer	1.86±0.09	1.16±0.04	0.81±0.04	3.83±0.10	4.22±0.10	0.39

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4.3 Impact of Soil management practices on soil Carbon Labile pools within soil fraction prior to seasonal cultivation.

The result of the labile C for the various soils separates (Table 4.3) revealed very low values for the various management practices prior to seasonal cultivation (Table 4.3a) and at the end of cultivation (Table 4.3b). This could be attributed to the rapid decomposition rate of organic matter resulting from high temperatures (34^{o}C and above) and the fast turnover time of the labile carbon (Brady, 1990 and Palm et al, 2001). The sand fractions from all the three management systems had the highest labile carbon content than the other fractions. This confirms the findings of Gregorich and Ellen, (1993) that carbon in sand fraction is always more labile than those in other fractions. The Clay fraction of manured soil showed the lowest labile C of 0.01 g/kg before cultivation. For all the management systems the labile C was higher at the season onset than at the end of the season. Generally, however the season's cultivation of maize did not seem to significantly affect the labile C of the soils. What was more evident was that across all management practices, the sand fraction had the highest labile C of about 0.11g/kg whereas the clay fraction had the least (0.01g/kg).The proportion of labile C in the silt fraction range from 0.01g/kg to 0.08g/kg.

These observations confirm earlier findings that the labile C is more associated with the unprotected C which should be found in the sand (Oades, 1984; Solomon *et al.*, 2000). Sand has low surface area reactivity and is less likely to react with SOC. Whereas this may be generally so expected, appreciably high amounts of non-labile C (calculated by difference) occur in all separate even in sand (Table 4.3).Soils in northern Ghana are derived largely from sesquioxides (Fe and Al oxides) and even sand grains may have Fe coatings (Yiran *et al.*, 2014).These Fe coatings can occlude OC and render them nonlabile.

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Table 4.3a Impact of Soil management practices on soil Carbon Labile pools within soil fraction prior to seasonal cultivation.

Site	Management	Soil Labile Carbon Pool (g/kg)					
		Sand-C_L	Silt-C_L	Clay-C_L	Sum C_L Fraction (a)	Whole soil Labile Carbon (b)	Difference (b-a)
Dimabi	**Manure**	0.11±0.001	0.06±0.0006	0.01±0.0003	0.18±0.001	0.19±0.00113	0.005
Nyankpala	**Manure**	0.10±0.002	0.01±0.0003	0.01±0.0003	0.18±0.0007	0.19±0.001	0.004
Savelugu	**Fertilised**	0.10±0.001	0.04±0.0012	0.01±0.0003	0.18±0.001	0.19±0.001	0.002
Savelugu	**Non-fertilised**	0.08±0.001	0.04±0.0010	0.01±0.0003	0.17±0.0001	0.18±0.002	0.009

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Table 4.3b Impact of Soil management practices on soil Carbon Labile pools within soil fraction after cultivation.

Site	Management	Soil Labile Carbon Pool (g/kg)					
		Sand C_L	Silt C_L	Clay C_L	Sum C_L fraction (a)	Whole soil labile carbon (b)	Difference (b-a)
Dimabi	**Manure**	0.10±0.001	0.06±0.001	0.01±0.0003	0.17±0.001	0.20±0.002	0.028
Nyankpala	**Manure**	0.09±0.002	0.08±0.002	0.01±0.0003	0.18±0.002	0.20±0.001	0.016
Savelugu	**Fertilized**	0.06±0.001	0.03±0.001	0.01±0.0010	0.10±0.021	0.20±0.012	0.025
Savelugu	**Non–Fert**	0.05±0.001	0.03±0.001	0.01±0.0010	0.08±0.031	0.19±0.013	0.027

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4.3 Labile, Non–labile carbon and Carbon management indices for three management practices and Uncropped soils in Northern Ghana.

A decline in organic carbon, labile carbon and non-labile carbon in all the three managed soils with respect to the soil from their respective reference site was evident in this study. The effect of site and management on labile C showed that labile C reduced by 0.045, 0.031, 0.0289 and 0.0361 g/kg for Dimabi, Nyankpala, Savelugu (fertilized) and Savelugu (Non-fertilised) respectively (Table 4.4).This agrees with the findings of Wu et al. (2005), that addition of fertilizers and organic amendments increases the organic carbon associated with different particle size fractions, and alters the allocation of C among fractions.

It is also observed that non-labile carbon forms about 97, 97, 96 and 95.8% of the total organic carbon of manure (Dimabi), manure (Nyankpala), inorganic fertilized and non-fertilized soils respectively, indicating a degradation of the soils carbon and nutrient reserves. This could be attributed to continuous cultivation with low input residues coupled with annual bush fires. The values of non–labile (N_L) indicate that the organic C is present in the passive form. Thus the soil is highly deteriorated resulting from rapid mineralization due to high temperatures (Kirschbaum, 2000). The lower organic carbon for manure management in Dimabi compared to the reference site was probably as a result of high organic matter decomposition facilitated by disruption of aggregates and high temperatures (Hassink, 1999; Kirschbaum, 2000). This could have been exacerbated by continuous residue removal and bush burning which normally is the practice within the site. Additionally, the quality of organic carbon used by the farmers is usually low due to improper management (Karbo *et al*., 1999). A similar observation was noticed at Nyankpala manure farm.

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Soil organic carbon from the three soil management systems were lower than that of the control field. The manure field showed least deviation in general. At Savelugu differences between total soils carbon for fertilized and unfertilized compared to their reference soil was about 10g/kg. These wide variations could be attributed to cultivation over the years. The lower CPI for non-fertilized field is indicative of the fact that such management systems do not facilitate organic matter storage, whereas, the manure fields with a higher CPI enhance organic matter retention and soil improvement (Blair, 1997). The Carbon Management Index (CMI) for non–fertilized field was 24.0, which indicates a soil with declining soil fertility, whereas, manure managed fields (Nyankpala and Dimabi) are being rehabilitated as suggested by their higher CMI (Blair, 1995).

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Table 4.4: Labile, Non–labile carbon and Carbon management indices for three management practices and Uncropped soils in Northern Ghana.

Management Practice	LabileCarbon (g/kg)	Non-labile Carbon (g/kg)	Total soil Carbon (g/kg)	Carbon Pool Index (CPI)	Lability of C (L)	Lability Index (LI)	Carbon Management Index (CMI)
	Dimabi						
Reference	0.23	10.74	10.97	-	0.02	-	-
Manure	0.19	5.64	5.83	0.53	0.03	0.85	49.8
	Nyankpala						
Reference	0.23	10.94	11.17	-	0.02	-	-
Manure	0.19	6.31	6.51	0.58	0.03	0.87	50.4
	Savelugu						
Reference	0.22	14.14	14.36	-	0.02	-	-
Fertilised	0.19	4.61	4.80	0.33	0.04	0.87	29.00
Non–fertilised	0.18	4.02	4.20	0.31	0.04	0.82	24.00

Reference refers to land left uncropped for several years (> 30 years)

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4.4 Management and SOC effects on maize yield

Figure 4.1 shows that maize yields are not always correlated with the TOC. Indeed, as shown, the yield of maize at Dimabi decreased with increasing TOC (Fig. 4.1 a). Except for Nyankpala where maize yield correlated well with TOC (Fig. 4.1b), in all the other cases, the positive correlation was weak (Fig. 4.1 C and D) and not significant. Therefore, the differences in yield are not largely determined by the TOC. The importance of organic carbon to plant growth is known. However, whole soil organic carbon correlates negatively with yield (Fig 4.1a), indicating that even though carbon is relevant to the growth of plant, nutrients must be released by decomposition for the plants to access. This negative correlation could mean that though organic carbon of Dimabi manure field is high relative to Nyankpala manure field, the quality of manure and the decomposition of the manure may not be complete to make nutrients readily available (Juma,1998). Swift *et al.* (1979) made the assertion that the rate of decomposition of manure is traceable to the residue quality. Thus the composition of the manure could be of low quality. Conversely, the whole soil organic carbon of Nyankpala soil (Fig 4.1a) showed a positive correlation (r=0.68) with the yield. This could also be indicative of the fact that the manure had undergone decomposition to some extent and thus had released nutrient to support yield (Swift *et al.*, 1979).

Maize yields varied across the sites and management practices (Table 4.5). The yield was lowest (1060) kg/ha in Savelugu under the no fertilizer management and was highest (2944) kg/ha under Savelugu under fertilized condition. The linear correlation between the yield and TOC among the other treatments were found to be positive but not significant with the values of R^2 being very low (Figure 4.1c and d). Karbo *et al.* (1999) indicated poor quality manure as prevalent in Northern Ghana.

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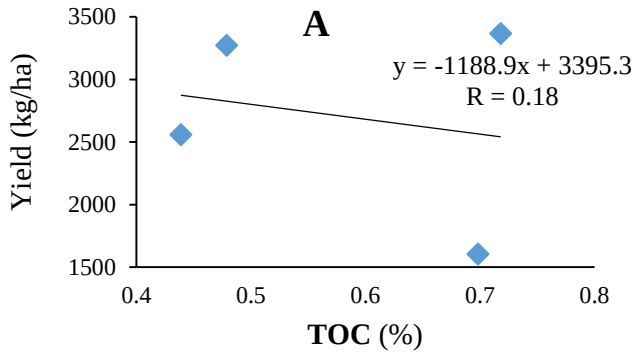
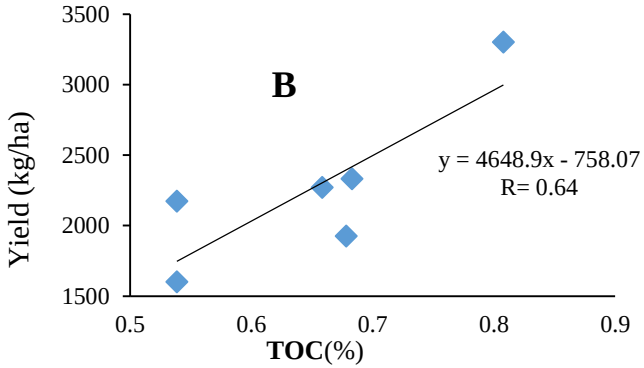
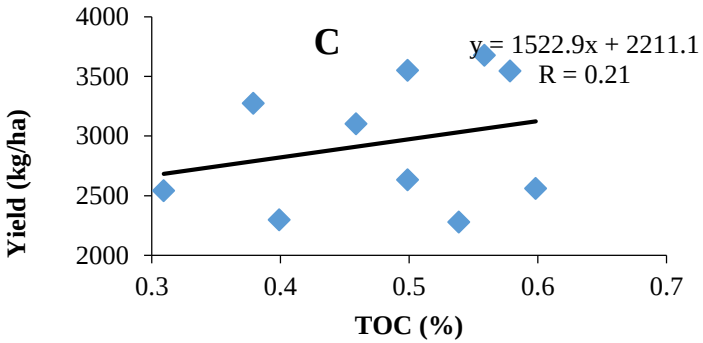
Dimabi Manure field



Nyankpala Manure field



Savelugu Fertilised field



Savelugu Non–Fertilised field

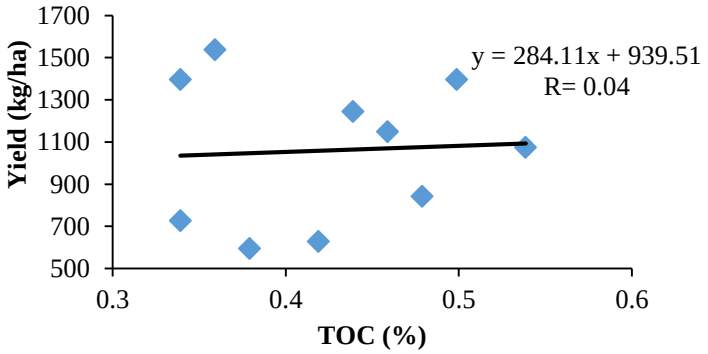


Figure 4.1: Relationship between maize yield and soil carbon for manure managed field (A and B), fertilised field (C) and non-fertilised field (D).

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Generally low yield was recorded under all the management practices (Table 4.5). However the fertilized field recorded the highest (2944.81 kg/ha) followed by Dimabi, Nyankpala and Savelugu non-fertilized field (Table 4.5).

Table 4.5: Average maize yields (kg/ha) under three management practices in Northern Ghana.

Site	Management practice	Yields (kg/ha)
Dimabi	**Manure**	**2701**
Nyankpala	**Manure**	**2267**
Savelugu	**Fertilized**	**2944**
Savelugu	**Non-fertilized**	**1060**

Generally, the labile carbon is low for all the treatments. There is a positive correlation between labile C and yield for all the treatments except for fertilized plot (Figure 4.2C). Figure 4.2A shows that there is a correlation between yield and labile carbon. It has R^2 value of 0.01.Figure 4.2B also shows a similar correlation between the labile carbon and the yield. It has R^2 value of 0.43.Figure 4.2C however shows a trend that is contrary to all the other treatments. The labile carbon correlates negatively with the yield. It recorded the highest yield of 3400 kg/ha when the labile carbon was as low as 0.02%. In Fig. 4.2D.the yield correlates positively with the % labile carbon. It has the lowest yield of 1100 kg/ha and $R^2 = 0.50$. The test confirmed that regression equation showing the relationship between yield and labile C, on manure and fertilized field was not insignificant at $p< 0.05$. This denotes that variability in yield of maize is directly regulated by labile C. Indeed

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the labile carbon in the fertilized soil correlates negatively with maize yield with r = 0.174 (Fig 4.2C). The labile carbon does not appear to be responsible for the yield. Rather, the fertilizer seemed to have obscured the native fertility of the soil which is already low. Thus, the effect of the native labile carbon is not evident. On the contrary, it is observed that the labile carbon of the non-fertilized fields correlated positively (r=0.50) with yield. This could mean that the labile pool is responsible for determining crop yield. From this observation, it is asserted that 96% of the organic carbon is in the passive form. Thus, the carbon that drives the yield is less than 5% of the total carbon, an indication that the soils are degraded.

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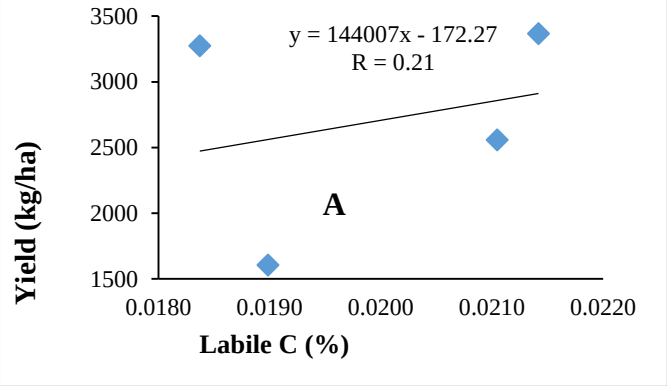
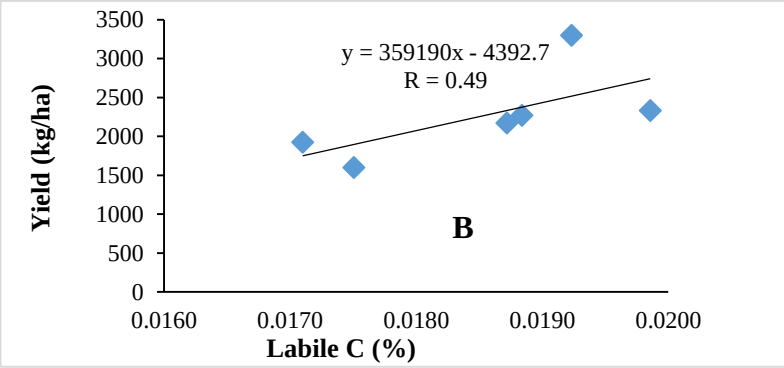
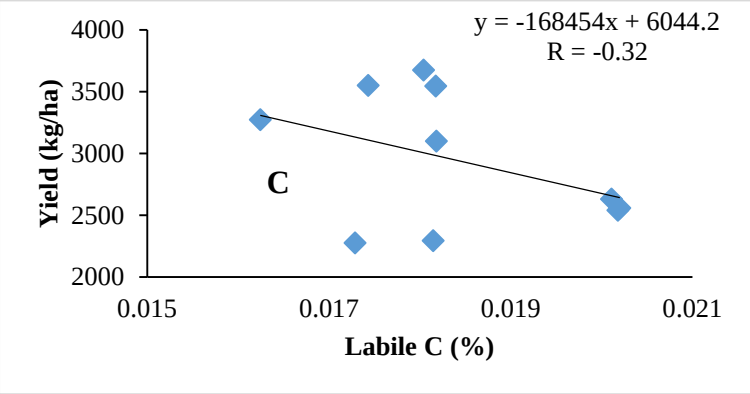
Dimabi Manure field



Nyankpala Manure field



Savelugu Fertilised field



Savelugu Non-Fertilised field

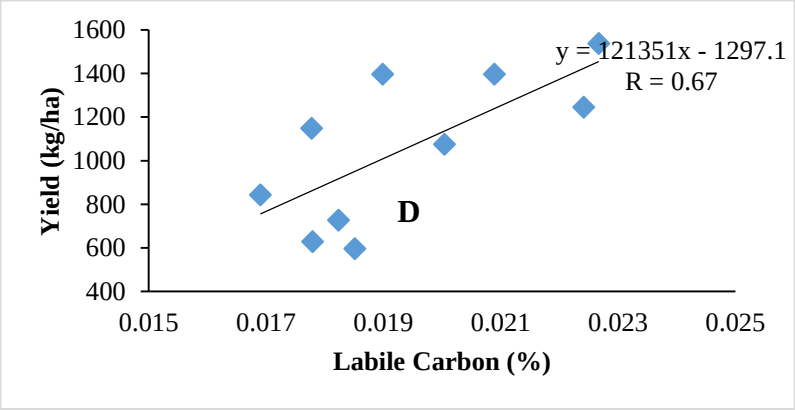


Figure 4.2: Relationship between maize yield and soil labile carbon manure applied field for (A and B), fertilized (C) non-fertilized field (D).

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4.5 The relationship between soil labile carbon and soil organic carbon content in manure, fertilized and non-fertilized fields.

One major aim of this study was to establish a relationship between the more difficult to determine labile SOC fractions and an easier and routinely determined soil variables. Here, two relations were explored. The first was the relationship between labile SOC and TOC

Figure 4.3A shows a polynomial curve indicating that percentage labile carbon decreases with increasing % total carbon. As the percentage labile carbon was nearing 0.02% the total organic carbon was 0.894%.The curve further decreased sharply from 0.02% labile carbon to 0.0185% when the total carbon was 0.969%, the curve then decreased gently to a labile carbon value 0.018% at a corresponding organic carbon value of 1.106. Figure 4.3B on the other hand shows a curve of the percentage labile carbon and total organic carbon. For Figure 4.3B the general observation was that, as the labile carbon increases the total organic carbon content of the soil also decreases accordingly. It was observed that as the % labile carbon decreased from 0.01986% to 0.01847% the organic carbon content also increased from 0.854% to 0.977%. The labile carbon content further decreased to 0.0179% and its corresponding organic carbon content was1.027%.This observation is similar to that of Figure 4.3A. Figure 4.3C also showed a similar trend as observed in figure 4.3a and b whereas the organic carbon is increasing, the labile carbon decreases correspondingly. Thus as the labile carbon was 0.02018% and remained the same whiles the organic carbon content increased from 0.827% to 0.883%. The labile carbon content then decreased to 0.01853% and then slightly decreased to 0.01702% while the organic carbon continue to increase to 1.108%. Finally, Figure 4.3D also shows a quadratic curve. The observation in this curve is similar to that of figure 4.3C.The organic carbon content continues to increase from 0.806

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% to 1.111%.The labile carbon content decreased slightly from 0.02% to 0.01695%.This observation is also similar to that in Figure 4.3B.

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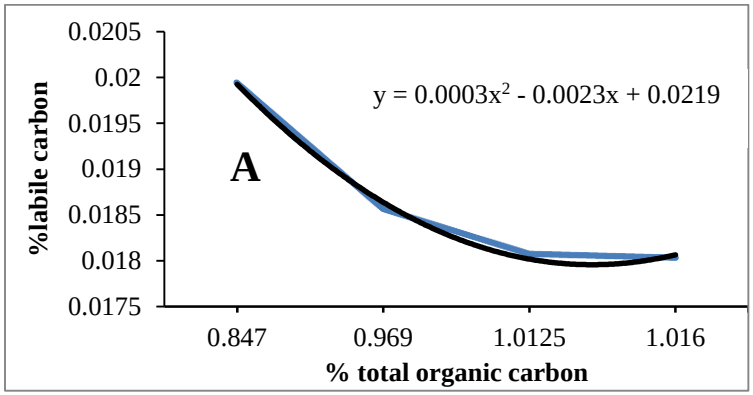
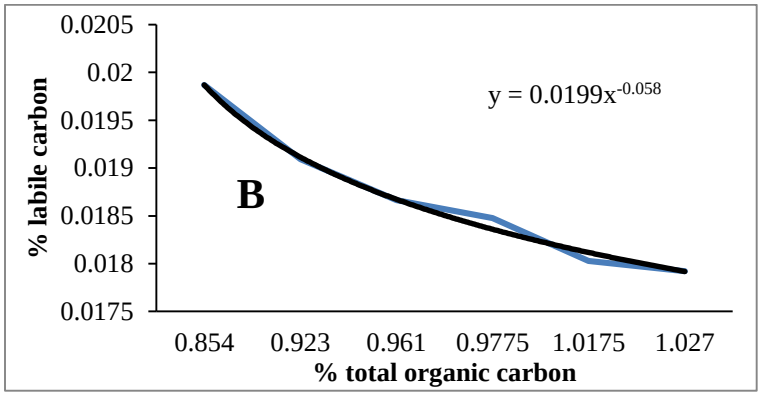
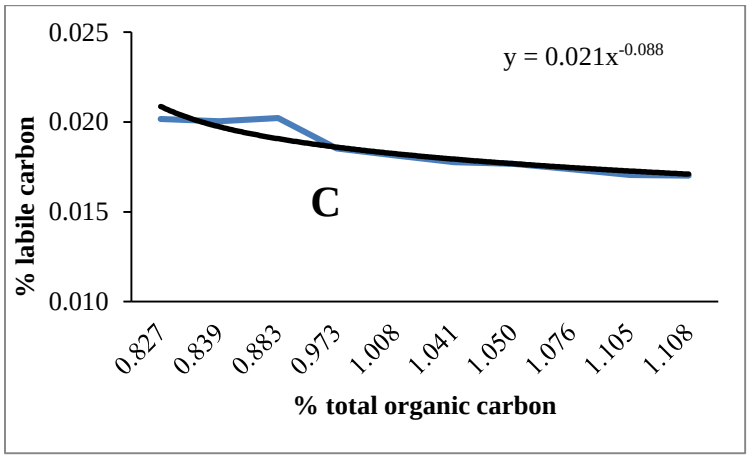
Dimabi Manure field



Nyankpala Manure field



Savelugu Fertilized field



Savelugu Non- fertilized field

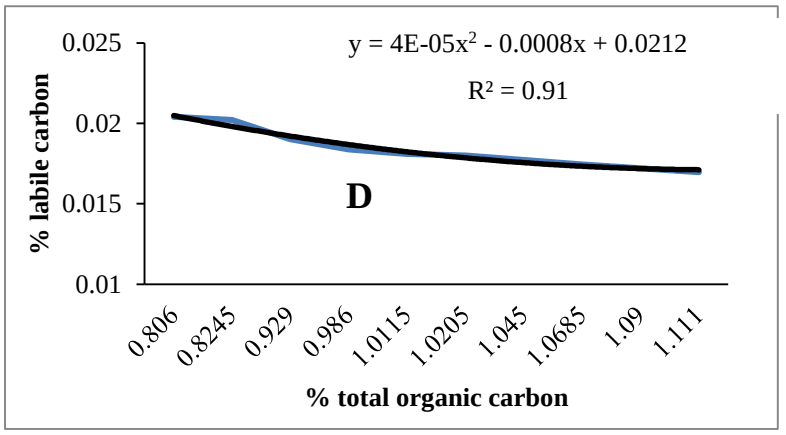


Figure 4.3: Relationship between labile carbon and total organic carbon manure applied field for (A and B), fertilized (C) non-fertilized field (D).

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4.6 Relationship between yield, total organic carbon and labile carbon

Multiple regression equations to estimate maize yield at the four sites based on TOC and C_L contents is presented in Table 4.6. Out of the 4 regression equations, only that for the non-fertilized field was significant ($p<0.05$). For the other three sites and managements types, TOC and labile carbon C cannot be used to explain grain yield since the relationship is not significant.

The coefficient of determination was 0.5, implying 50% of the variation in yield can be explained by TOC and labile C. Given that the relationship between grain yield and TOC and labile C are site specific, these equations may not be applicable in other environments.

Table 4.6: Multiple regression equations of yield, total organic carbon (TOC) and labile carbon (C_L).

Site	Management	Regression Equation
Dimabi	Manure field(RFP)	$\text{Yield} = 269.365 - 1431.52\ \text{TOC} + 163736.14\text{C}_\text{L}$
Nyankpala	Manure field(RFP)	$\text{Yield} = -4171.77 + 3778.39\ \text{TOC} + 214660.1\text{C}_\text{L}$
Savelugu	Fertilised field(RP)	$\text{Yield} = 5350.372 + 1632.467\ \text{TOC} - 173494\text{C}_\text{L}$
Savelugu	Non-fertilised field TR	$\text{Yield} = -1984.31 + 1174.76\ \text{TOC} + 131032.5\ \text{C}_\text{L}$

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CHAPTER FIVE

5.0 SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

The primary purpose of this study was to evaluate the effects of farmer-based management systems, namely: manure application, inorganic fertilizer application and conventional practices on organic matter pools and maize yield in northern Ghana. Results from the studies have shown that total organic carbon and the labile carbon (which is associated with nutrient dynamics in the soil) decreased in the order; manure application >> inorganic fertilizer application> no fertilizer application.

It is also established from the results that the proportion of non–labile carbon to total carbon is in the order of 97, 97, 98 and 99% for manure field (Dimabi), manure field (Nyankpala), Savelugu inorganic fertilized (Savelugu) and conventional fields (Nyankpala) respectively. In addition, CPI value which indicates the extent of degradation or rehabilitation of a particular management system are in the order Nyankpala > manure > Dimabi manure field > Savelugu fertilized > Savelugu non fertilized field. The CMI which is the measure of the rate of change in soil carbon dynamics of a management system with regard to a virgin (reference) sample was in the order; 50.6 >>> 47.6 >> 39.9 > 24.9 for Nyankpala manure field, Dimabi manure field, Savelugu fertilized, and Savelugu fertilized system respectively.

The study also revealed that the inorganic fertilizer managed system gave the highest maize yield compared to the other management systems. This was followed by organic manure system, with

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conventional practice producing the lowest yield. Finally, it is also established that the relationship that exist between the labile carbon fraction and the organic carbon content could be described mathematically as (C_L=0.0031TOC^2-0.0023TOC+0.0219) and (C_L=0.0199TOC$^{-0.058}$) for Dimabi manure field and Nyankpala manure fields respectively. And that of Savelugu fertilized field and non-fertilized fields were (C_L=0.02TOC$^{-0.088}$) and (C_L=4E-0.00005 TOC^2-0.0008 TOC+0.0212).These equations therefore could be used to estimate labile carbon fraction for similar scenarios when total organic carbon values are determined. These equations are however site specific.

5.2 RECOMMENDATIONS

Based on the results obtained from this study, the following recommendations are made:

1) The study should be repeated in the coming seasons to have long-term data to compare with due to rapid changing climatic conditions.
2) The study should be extended to various localities within the northern region with different soil types.
3) To increase the labile carbon content of the soil, woody crops such Pigeon pea should be considered as a fallow crop which would fix nitrogen in the soil as well as incorporated into the soil to enrich carbon content.
4) The study has shown that the organic carbon levels in the area is very low, agroforestry is therefore recommended. Thus, plant species that can enhance the organic matter stocks.

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5) Finally, models such as CENTURY could be used to simulate soil carbon degradation or rehabilitation over longer years with different environmental conditions. This will provide outputs that will lead to taking good management decisions on how to manage the soils properly.

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APPENDICES

APPENDIX I

REGRESSION ANOVA FOR DIMABI

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	267704.3334	133852.2	0.077646	0.93
Residual	1	1723884.305	1723884		
Total	3	1991588.639			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	269.3653418	10205.28442	0.026395	0.983201	-129401.0679	129939.8
Labile C	163736.139	508987.4511	0.32169	0.801862	-6303562.623	6631035
Total C	-1431.516939	5277.575787	-0.27125	0.831377	-68489.4754	65626.44

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APPENDIX II

REGRESSION ANOVA FOR NYANKPALA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1329860	664929.9	6.386514	0.082949
Residual	3	312344.1	104114.7		
Total	5	1642204			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-4171.77	2561.372	-1.62873	0.201858	-12323.2	3979.656
Labile C	214660.1	149994.2	1.431122	0.247783	-262689	692008.7
Total C	3778.393	1544.37	2.446559	0.091961	-1136.48	8693.269

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APPENDIX III

REGRESSION ANOVA FOR SAVELUGU(LANGA)FERTILIZED

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	680087.2	340043.6	1.193634	0.35806
Residual	7	1994167	284881.1		
Total	9	2674255			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5350.372	2556.996	2.092445	0.0747	-695.961	11396.71
Labile C	-173494	131791	-1.31643	0.229492	-485130	138142
Total C	1632.467	1884.632	0.8662	0.415081	-2823.98	6088.913

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APPENDIX 1V

REGRESSION ANOVA FOR SAVELUGU NON FERTILIZED FIELD

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	589332.4	294666.2	4.397867	0.057937
Residual	7	469014.5	67002.07		
Total	9	1058347			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1984.31	1122.757	-1.76735	0.120501	-4639.21	670.5901
Labile C	131032.5	44314.96	2.956846	0.0212	26244.3	235820.8
Total C	1174.761	1272.697	0.923048	0.386692	-1834.69	4184.211